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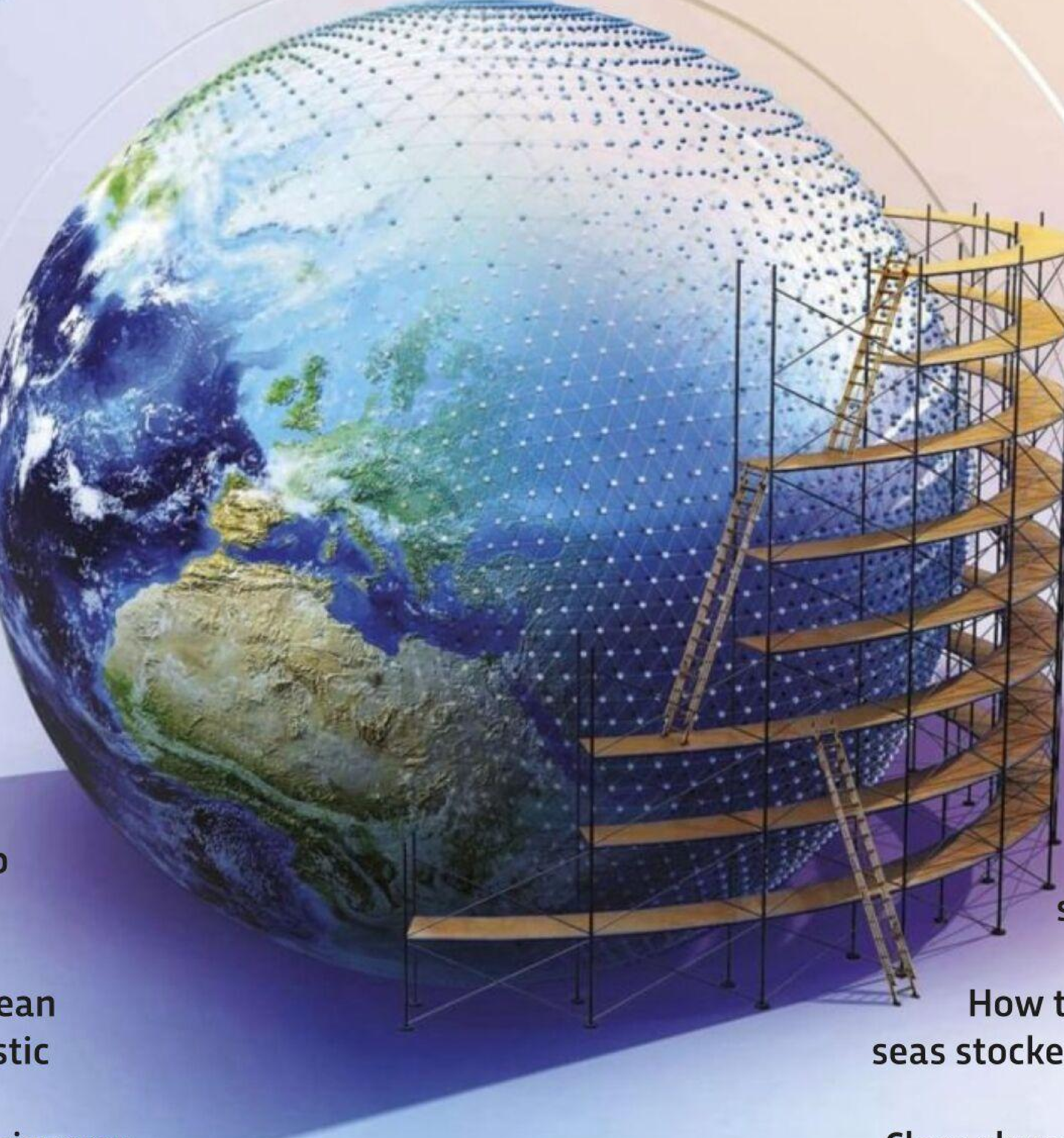
HOW SCIENCE CAN FIX THE PLANET



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Mega-tech to stop global warming

Genius ideas to clean the oceans of plastic

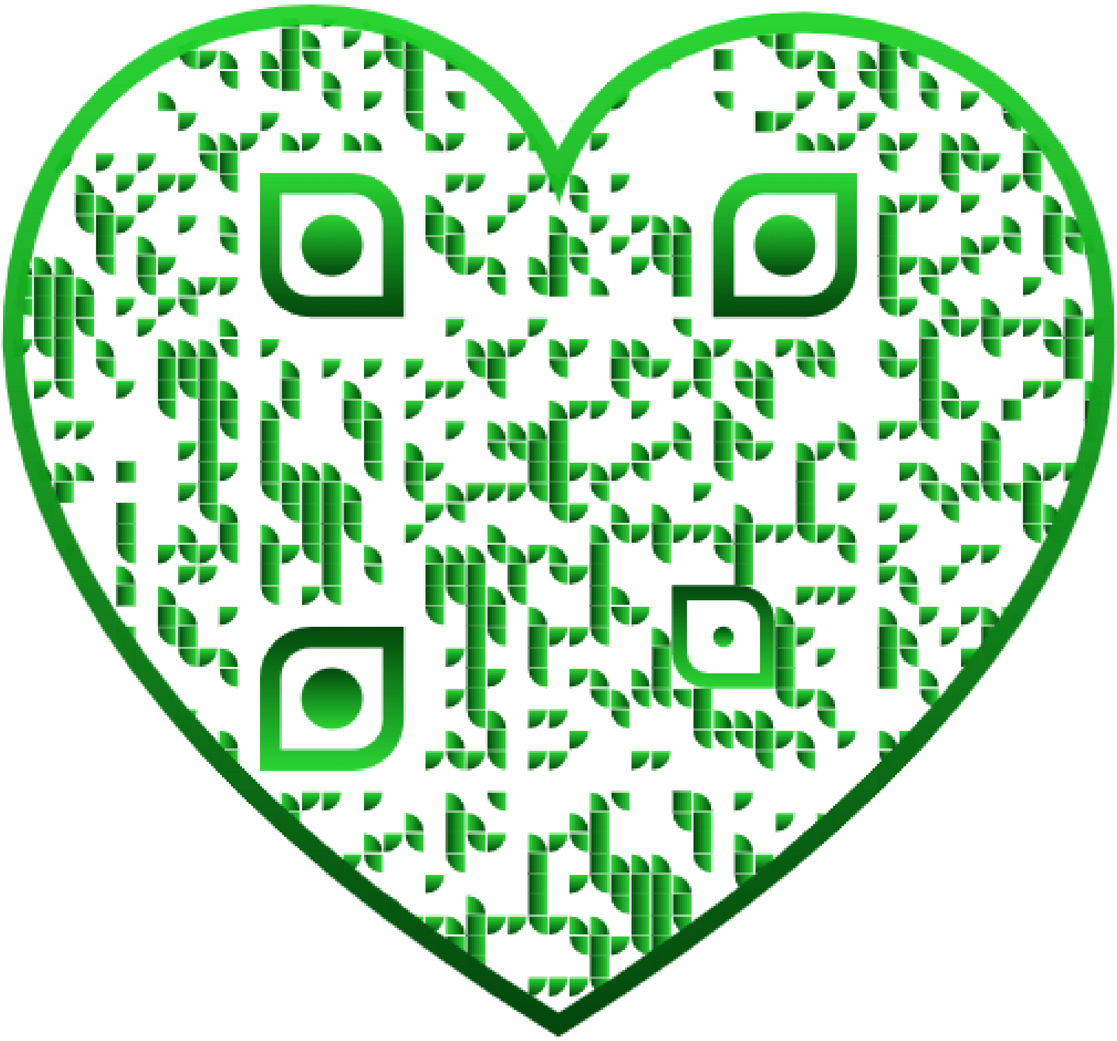
Meet the plant whisperer and coral matchmaker

Best diet for Earth

8 ways to stop floods

How to keep the seas stocked with fish

Clear sky solutions to cut down air pollution



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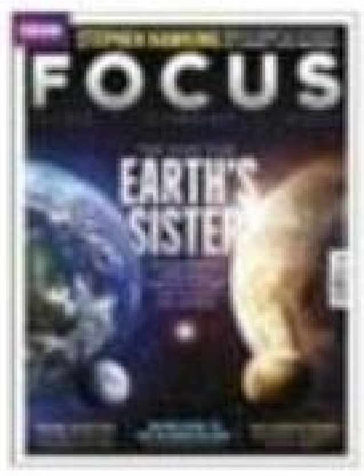

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Saving Planet Earth

Anyone aged 18 or over has lived through all 10 of the warmest years on record. And, by 2100, temperatures are expected to rise by around 3.2°C. Stats like these are worrying. We know that rising temperatures are killing coral reefs, causing desertification, whipping up super-storms and creating severe floods.

Some people are resigned to the dangers of this changing world. But others are looking for ways we can fight climate change. Former President Obama said in 2015: "More drought, more floods, rising sea levels… That's one path we can take. The other path is to embrace the human ingenuity that can do something about it."

Scientists around the world are researching techniques that could save Earth – from large-scale geoengineering projects (page 58) to more modest inventions that will cut urban air pollution (page 72) or allow us to keep the lights on while reducing carbon emissions (page 53).

The good news is that, when it comes to the crunch, we're good at sorting out problems. Back in the 1970s, scientists realised that acid rain was eating away buildings and turning lakes into death traps for wildlife. The cause was mostly the sulpher dioxide being released by human activities. So changes were made. Today, cars have catalytic convertors fitted and power plants use 'scrubber' technology to reduce the amount of sulphur dioxide released into the atmosphere.

Another example of our ingenuity is how we're dealing with the continent-sized hole in the ozone layer. After a 1974 paper and subsequent satellite data revealed the ozone-destroying effects of chlorofluorocarbons, CFCs were phased out under the 1987 Montreal Protocol. So it goes to show that we can make a difference when we set our minds to it. This special issue is packed with articles looking at the global problems facing us and what we can do to fix them to ensure the survival of *Homo sapiens* and all the other species we share this incredible planet with.

Daniel Bennett, Editor

CONTENTS

PROBLEM 1

HUMAN IMPACT

Defusing the population bomb 09
What's the best diet for the planet? 14
How to keep the tap on 22
There are plenty more fish in the sea 24
The plant whisperer 30
The green great wall 34
8 ways to beat the floods 36
The new herbalist 38

PROBLEM 2

ENVIRONMENTAL DAMAGE

How to solve the plastic problem 44
Power tools to save the planet 53
5 mega ideas to fix the climate 58
Will geoengineering start a climate war? 60
The cloud chaser 68
A breath of fresh air 72
The unsung eco-heroes 78

PROBLEM 3

EXTINCTION

How to beat mass extinction 84
7 ways species evolved to survive 92
The coral matchmaker 94
Should we let pandas go? 98

98

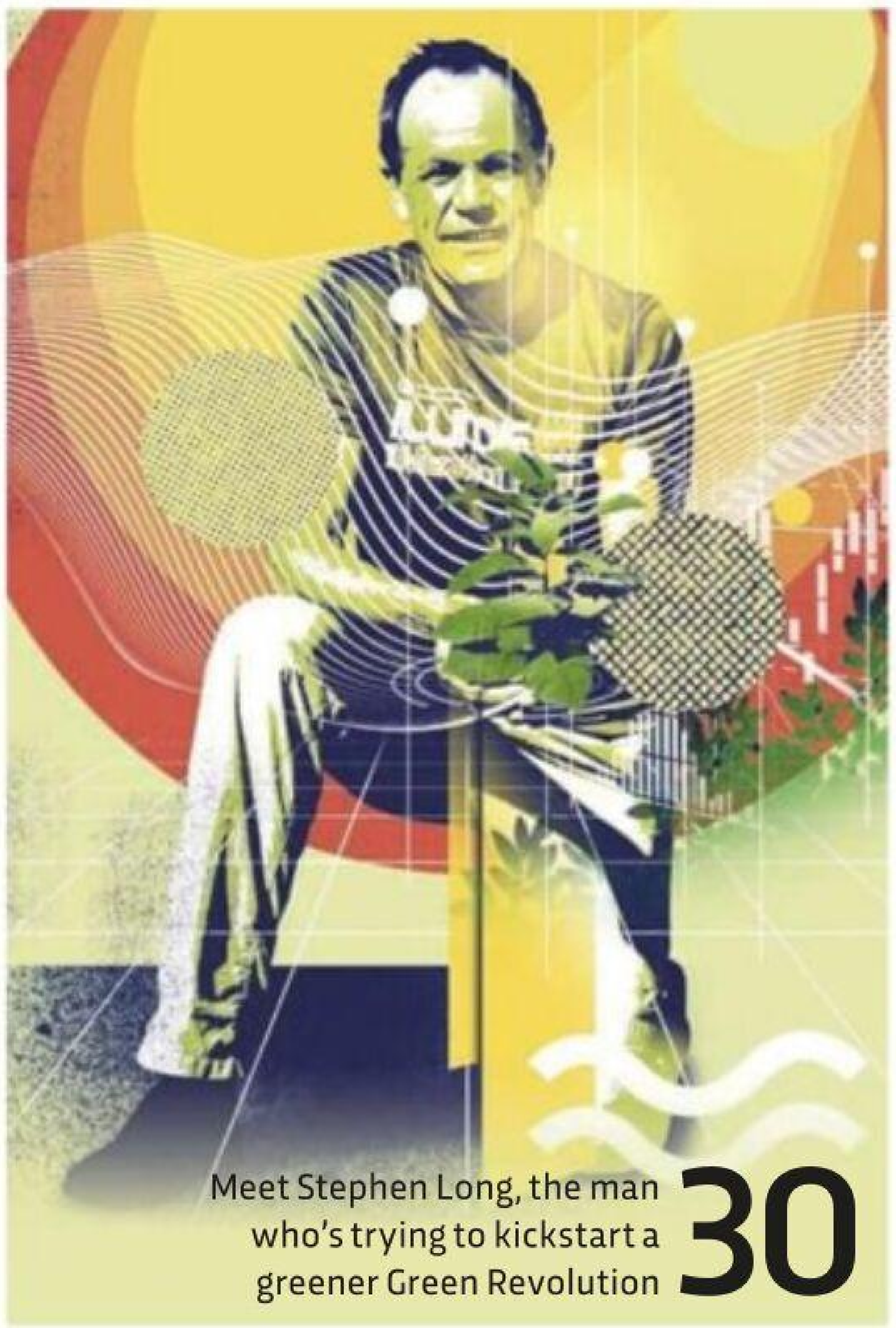
Pandas: no sense of self preservation

60

Mend the climate, start a war – the fallout of fixing our atmosphere

09

Can we feed the ever-growing global population?



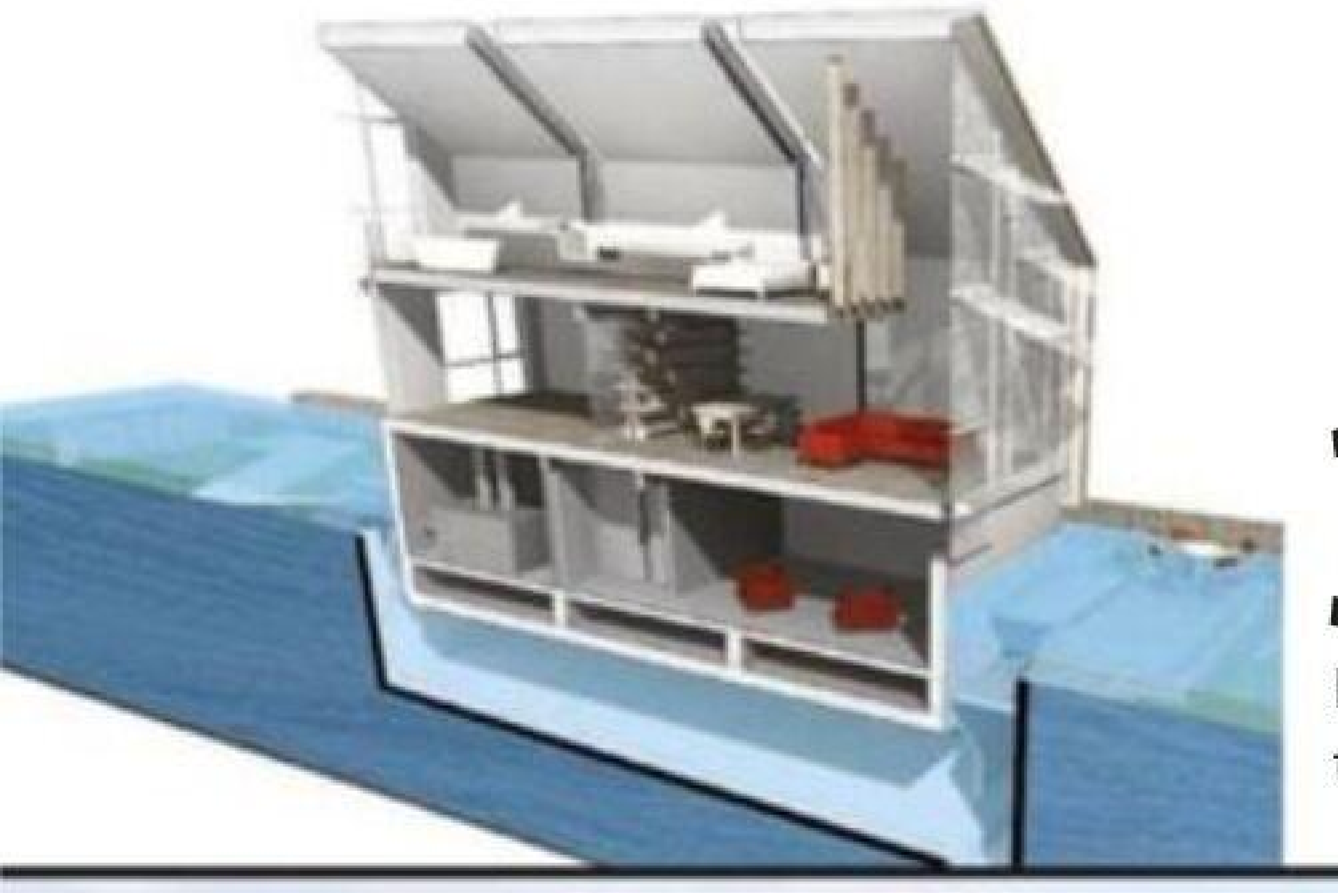
Meet Stephen Long, the man who's trying to kickstart a greener Green Revolution 30

58

The massive, mad-cap schemes to save the climate

44

The search for a better alternative to plastic



36
How to stay above the rising tides

DROUGHT TOLERANT VARIETIES
IRRI 161
(NSIC 2011 Rc274)

92
The ways wildlife adapts to humans

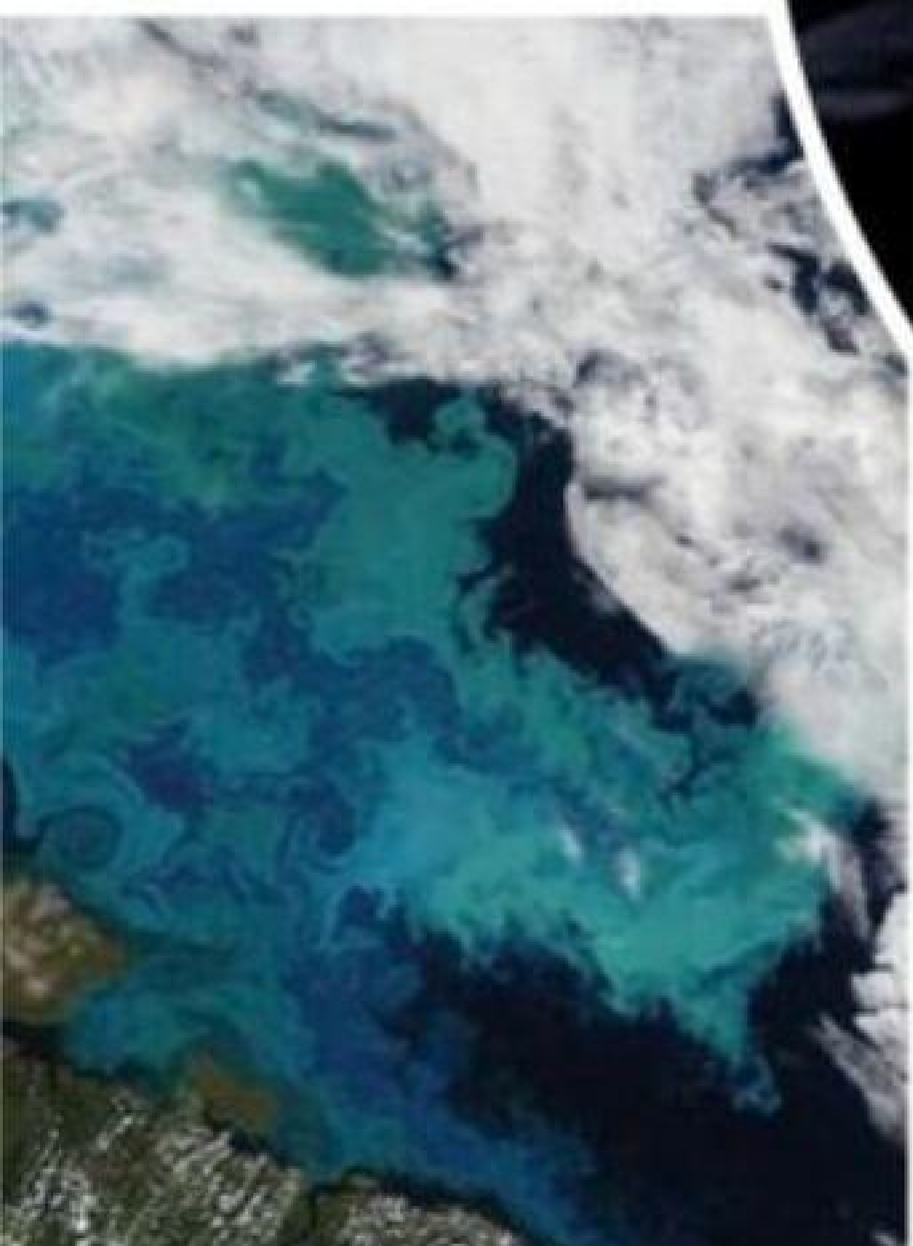
53
Keep a clean conscience and a cleaner exhaust

84
Ensuring a future for Earth's plants and animals

78 Why we need to protect bogs, grasslands and deserts

72
Air pollution: the invisible threat

24
How to keep the seas stocked with fish



14
Your next meal needn't be Earth's last

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PROBLEM 1

HUMAN IMPACT

As difficult as it is to admit, to a greater or lesser extent we're responsible for many of the problems the planet is currently facing. And although Earth may ultimately be able to adapt to the maladies we've inflicted upon it, if we don't act soon to at least alleviate the symptoms, it won't be long until we start to suffer the catastrophic consequences. But as bleak as the outlook appears, there are a few slivers of hope shining in the darkness.

SOLUTIONS FOR

OVERPOPULATION – DEFUSING THE POPULATION BOMB P9
FOOD PRODUCTION – WHAT'S THE BEST DIET FOR THE PLANET? P14
WATER STRESS – HOW TO KEEP THE TAP ON P22
OVERFISHING – THERE ARE PLENTY MORE FISH IN THE SEA P24
FAMINE – THE PLANT WHISPERER P30
DESERTIFICATION – THE GREAT GREEN WALL P34
FLOODS – 8 WAYS TO BEAT THE FLOODS P36
SUPERBUGS – THE NEW HERBALIST P38

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DEFUSING THE POPULATION BOMB

Despite all the doomsday predictions, over-population will not cause our demise. Over-consumption could instead. But, our ingenuity will save us

WORDS: **FRED PEARCE**

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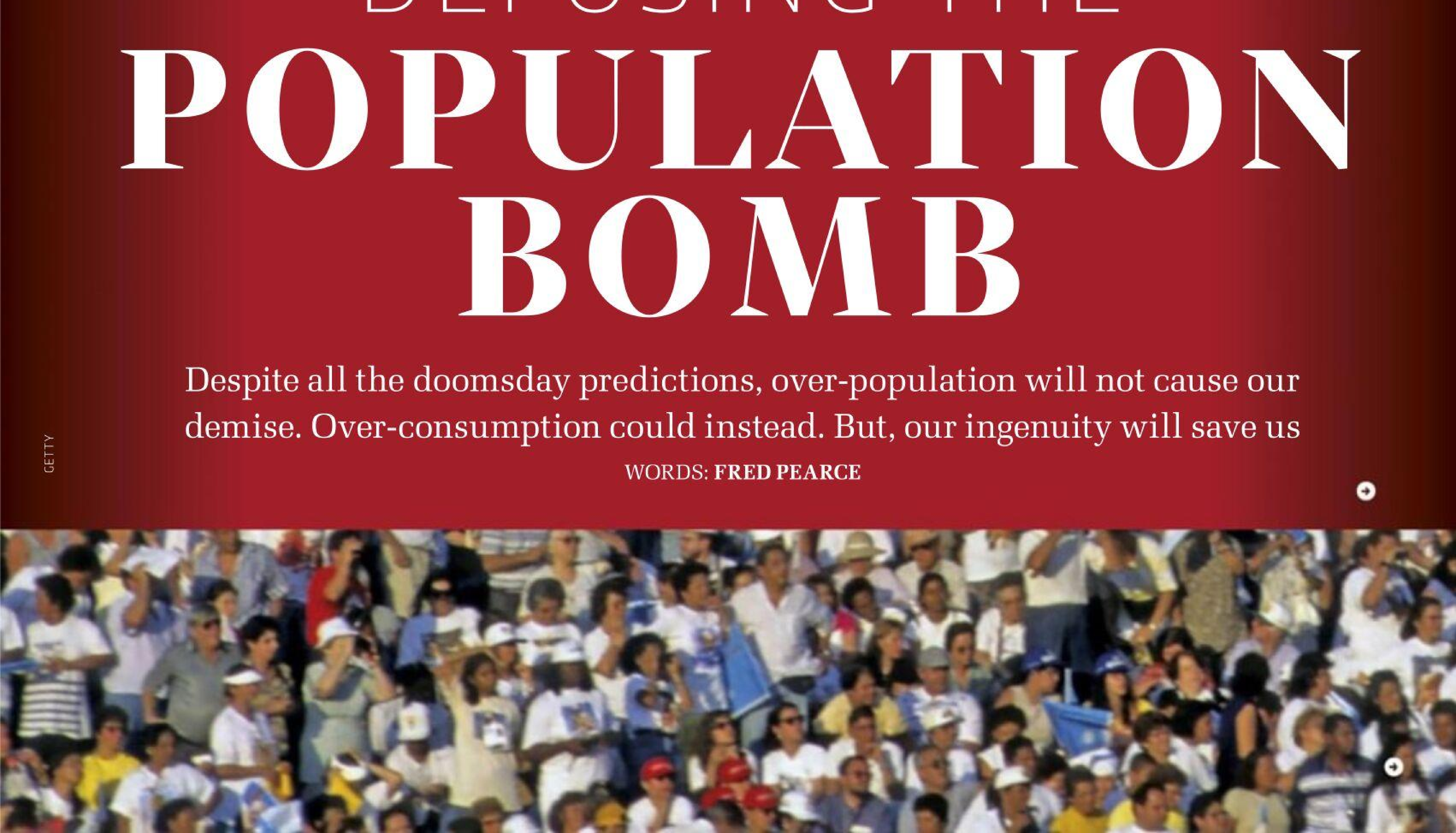


The numbers are scary. The world's population is soaring. It passed seven billion in 2011, four times the number just a century ago, and is now over 7.6 billion. UN statisticians predict more than 11 billion by the end of the century. Make that another three Chinas to feed.

And with every citizen on the planet demanding a better life, with greater consumption of the planet's scarce resources, scientists fear we are rapidly approaching dangerous 'planetary boundaries', beyond which food supplies give out, ecosystems break down, global warming accelerates, and – maybe – our global civilisation, with its many comforts, goes into a tail-spin.

The stakes could not be higher for *Homo sapiens* on Planet Earth. But, if you read the stats carefully, there is hope.

> **Women are voting with their wombs. They are having fewer children – on average half as many as their grandmothers did**

We are not doomed – for two reasons. Firstly, because the population explosion is actually being defused. By the end of the century our numbers could be stable or even declining. And, secondly, because the idea that our greed will demand ever more resources, and produce ever more pollution, is also flawed. It could happen that way, but it need not. The negotiations about climate change in Paris back in 2016 showed how things could get better – particularly if the US sign up again.

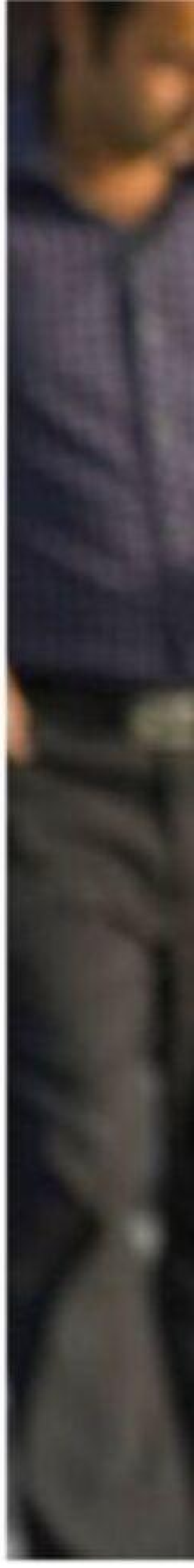
Here is the good news on population. Women are having fewer children – on average half as many babies as their grandmothers did. The world fertility rate – the number of children born to the average woman – has fallen from 4.9 children per woman in the early 1960s to 2.4 today. It continues to fall. That figure is getting close to the global long-term replacement level of 2.3 children per woman, which allows for the fact that not all girls make it to adulthood. Almost half the world is living in countries with rates already below replacement level. That means that without inward migration, their populations are set to start falling.

The population of the US is rising now largely because of the arrival of new migrants, who tend to be young and to have larger families than their hosts, at least in the first generation. In recent years, Europe has been full of concern about the large numbers of refugees coming from Syria, Afghanistan and elsewhere. But the truth is that without a steady flow of migrants, countries, such as Germany and Italy, would already be shrinking. Germany's fertility rate today is just 1.4.

Families averaging well below two children are the norm across most of the Caribbean, a swathe of the Far East from Japan to Vietnam, and in much of the Middle East, such as Iran. That's a big surprise to many. Behind the veil, Iranian women have cut their family sizes from around eight in the 1980s to 1.8 in 2016. Women in Tehran have fewer children than those in New York or London.

FALLING FERTILITY

Even the poorest nations are having fewer children. Bangladeshi women have on average only 2.4 children. In India the figure is 2.5, and in Brazil – despite the preaching of the Catholic Church against contraception – it is down to 1.8. Of course,



RIGHT: Iranian women are having fewer children. They had around eight in the 1980s, today the average is only 1.8

BELOW: The International Rice Research Institute (IRRI) aims to reduce food poverty, and is renowned for having developed rice varieties in the 1960s, which pre-empted the famine in Africa and contributed to the Green Revolution

DROUGHT TOLERANT VARIETIES
IRRI 161
(NSIC 2011 Rc 274)

ALAMY, GETTY/BLOOMBERG

China had a one-child policy for the past 35 years. It proved so successful that the country is now scared of an ageing population and last fall announced a new two-child policy.

The main exceptions, where fertility remains above four children, are some parts of the Middle East and Africa. But the trend is near-universal elsewhere, and only rarely involves forced population policies. Women are voting with their wombs for smaller families.

The biggest reason is simple. Diseases like measles that once killed most children are retreating fast. Most kids now get to grow up. World population quadrupled in the 20th century, largely as a result of this health revolution. Now, women are adjusting by having fewer children.

There are other reasons, too. Better educated women (or even just those watching TV shows featuring the lifestyles of their sisters in richer countries) want a life beyond child-rearing. And reliable modern contraception helps hugely.

In much of the world, populations continue to rise, but largely because most people are still young and fertile – products of the 20th-century baby boom. As the baby boomers age, there will be fewer women of fertile age, and populations will stabilise. Our longer life expectancies will slow, but won't stop this.

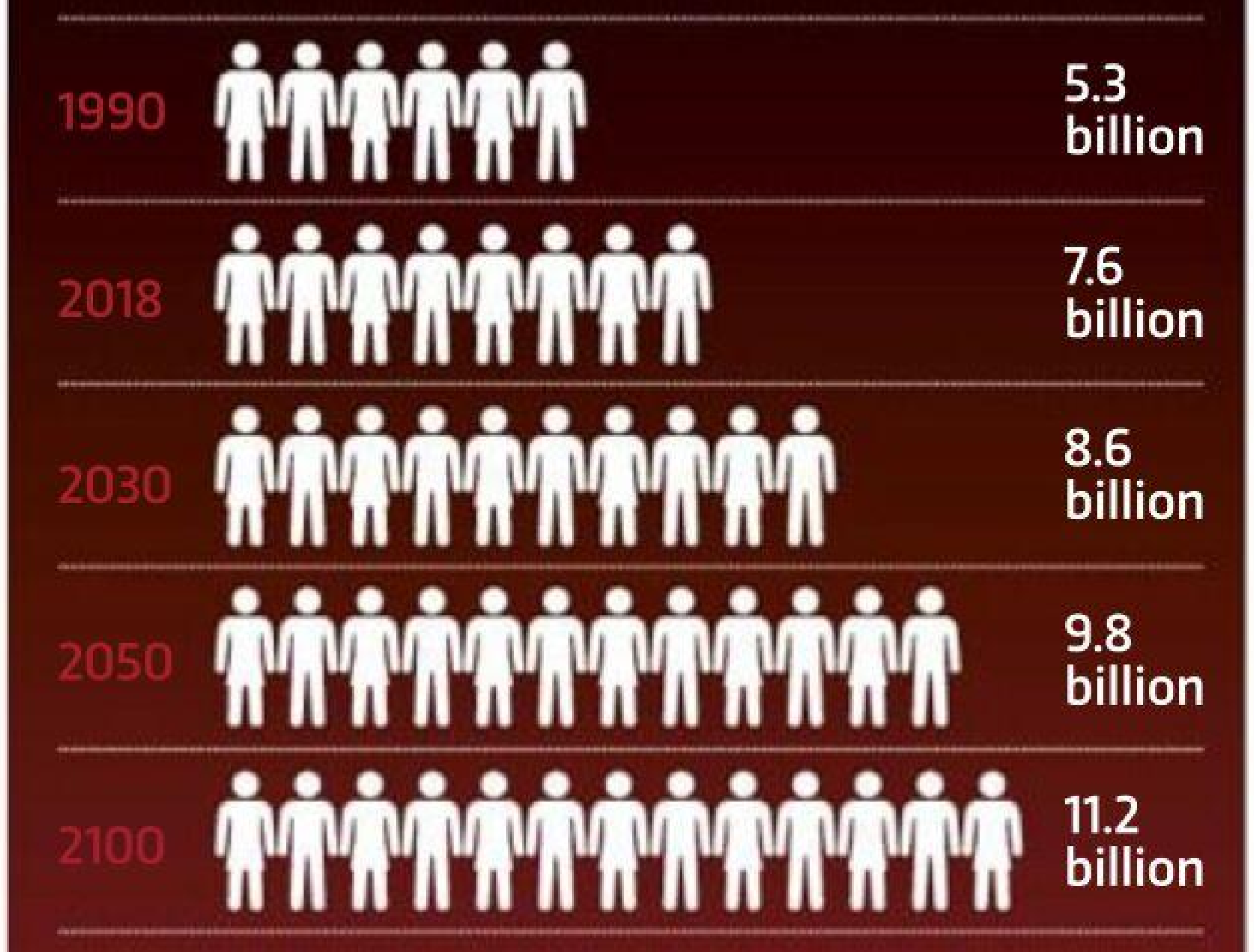
The only real question is how fast this will happen, and here there is disagreement. UN statisticians guess that Africa's current high fertility rates will decline only slowly, while the very low fertility in many countries today will creep back up. But Joseph Chamie, former chief UN demographer, says he expects continued rapid fertility decline in Africa, and sees "no compelling case" to expect rising fertility elsewhere. Many demographers agree with him that we are on a path to a stable world population by later this century, perhaps at below 10 billion.

CONSUMPTION CONUNDRUM

Will this be enough to save the planet from the ecological Armageddon that some predict? The impact of humans on the planet is the result of three things: population numbers, what those people consume, and the way they produce what they consume. So how are we doing?

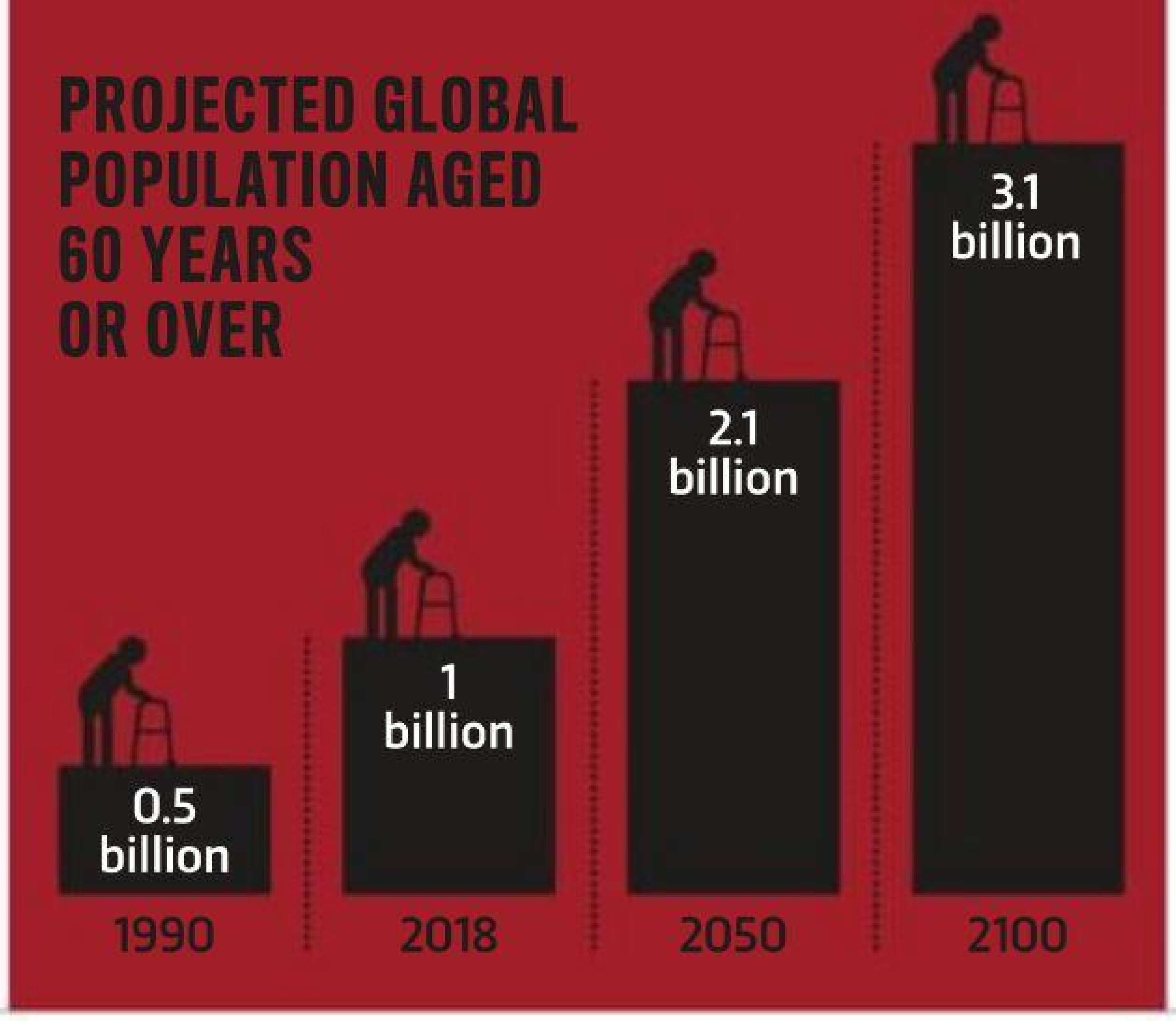
Human numbers, as we have seen, ➔

PROJECTED WORLD POPULATION UNTIL 2100



5% OF THE WORLD'S POPULATION LIVE IN THE INDIAN STATES OF BIHAR, JHARKHAND AND WEST BENGAL

PROJECTED GLOBAL POPULATION AGED 60 YEARS OR OVER



A solar power microgrid in the village of Dharnai in Jehanabad, India. The Indian Prime Minister was one of the key figures that helped to form the International Solar Alliance between 121 countries, which aims to reduce reliance on fossil fuels

are still rising. But the rise is slowing. The 'population bomb' is being defused. So the big problem now is less about our numbers and more about our consumption. Even in rich countries we continue to consume more. And poor countries have a long way to go if they want to catch up. Economists predict the world's economy will grow by 400 per cent by 2050. If so, only a tenth of that growth will be due to rising human numbers.

So right now it looks like we have a 'consumption bomb'. And that is not being defused. So we need to look at the third element in the impact equation: how we produce what we consume. And here there is good news. In a crisis, humans invent stuff.

In the 1970s, the biologist Paul Ehrlich wrote a famous book, *The Population Bomb*. He said the world's population was going to double in a generation, and food production wouldn't keep up. Many agreed with his prediction: "the

GETTY/BLOOMBERG

Getting richer need no longer mean getting dirtier. In 2014, the global economy grew by 3%, but emissions were stable

battle to feed humanity is over. Hundreds of millions of people are going to starve to death."

Well, world population did double, but so did food production. Science delivered new high-yielding varieties of rice and corn – a 'Green Revolution' that has kept the world fed.

Can we repeat the trick in other areas? Take climate change, which attracts the same doomsday headlines as food shortages did half a century ago. The story is simple. The world is using ever more energy, and in generating it we pump ever more planet-warming gases, such as carbon dioxide, into the atmosphere. We seem set to exceed the 2°C (35°F) of warming deemed safe. We are already half way there.

Again, it's scary. But again technology may be coming to our aid. Thanks to better energy efficiency and new forms of low-carbon energy, like solar and wind power, Europe's emissions have been falling for more than two decades. The US's emissions started falling in 2007, and China expects to peak before 2030. In 2014, the global economy grew by 3 per cent, but emissions were stable. Getting richer need no longer mean getting dirtier.

Countries made more promises for emissions reductions at the Paris climate talks. Researchers at the Potsdam Institute for Climate Impact Research in Germany reckon those promises could cut emissions for every unit of electricity generated by an average of 40 per cent.

There are similar trends in our use of natural resources, from iron ore to plastics. Futurologist Jesse Ausubel of Rockefeller University is convinced that the world is turning a corner, and that advances in technology can achieve much more to save the planet than further curbs on our fertility, or exhortations for us to lead more frugal lives. The global economy is 'dematerialising', he says.

We cannot be sure that this dematerialisation will come in time to prevent global breakdown, says Johan Rockstrom, of the Stockholm Resilience Centre, who analyses the limits to how we can use the Earth's resources. For instance, the green revolution caused massive increases in nitrogen pollution from fertilisers and our use of water (see page 22). Both are now growing threats.

But the good news, says Rockstrom, is that while extra people undoubtedly put extra pressure on the planet, we do still have options for doing things much better. We have to be smart enough to find and use those options. Sure, we have more mouths to feed these days, but we also have more hands to work and more brains to think. So they may yet be our planet's salvation.

BBC RADIO 4

Listen to an episode of *Glass Half Full* on global population **bbc.in/2qdlhc1**

Fred Pearce is an award-winning writer and author. His next book *Fallout* is due out in June.

WHAT'S THE BEST DIET FOR THE PLANET?

To support the burgeoning population we're having to make some tough choices about what we consume and the way we produce it. But the never-ending deluge of information about our food choices can be baffling. So should we all become vegan or can we really have our steak and eat it?

WORDS: **JOSH GABBATISS**

Diet can be a contentious issue, subject to the forces of personal ethics, religious beliefs and health concerns. But when it comes to the environment, for many people it's an open-and-shut case. "The evidence is all there, you just need to look for it," my vegan friend told me recently.

The thing is, although I'm not a vegan myself, I suspect he's probably right. While I'm quite sure this isn't the stated aim of most vegans, abstaining from animal products does seem to give you the moral high ground in the environmental stakes. I've watched *Cowspiracy*, I know the deal. At the same time, I'll admit to being a little put off by how self-assured some people seem in their dietary choices. Seldom does all the evidence point in one direction, and when considering something as multifaceted as the global food system, perhaps it's unwise to generalise.

In recent years, scientists and the public have become more aware that the food we eat can have negative impacts on the planet. With this in mind, it's worth asking – whichever side of the fence you're on – whether the evidence really is 'all there', and whether there exists a diet that is objectively best for the environment.

This is not a straightforward issue. According to figures from the Consultative Group on International Agricultural Research, one-third of our greenhouse gas emissions come from agriculture. But that's just one factor. Our food system is also the leading cause of deforestation, land-use change and biodiversity loss in the world. Then there's overfishing, pollution, groundwater depletion, excessive fertiliser

GETTY

use and pesticides to contend with as well. With all these issues to consider, a 'sustainable' diet might mean different things depending on who you talk to. But certain trends cut through the noise, most notably an emphasis on more plant-based diets.

The idea that vegetarianism is good for the planet is relatively new. Back in 1971, a book by Frances Moore Lappé entitled *Diet For A Small Planet* suggested that world hunger could be remediated if less emphasis was placed on meat in Western diets. But skip forward 46 years and official guidelines everywhere from the Netherlands to the US emphasise lower meat consumption for a healthy body and a healthy planet. Vegetarianism has gone mainstream. In a report from the US-based 2015 Dietary Guidelines Advisory Committee, the authors concluded: "Consistent evidence indicates that, in general, a dietary pattern that is higher in plant-based foods… and lower in animal-based foods is more health promoting and is associated with lesser environmental impact than is the current average US diet."

While plant-based diets have now been normalised, vegetarians and vegans are still relatively thin on the ground

These are not empty words. Study after study has demonstrated the beneficial effects of a plant-based diet for the environment. A paper published last year in *Proceedings Of The National Academy Of Sciences* concluded that a mass switch to vegetarianism would reduce food-related greenhouse gas emissions by 63 per cent, while even just sticking to global health guidelines for meat consumption (laying off the burgers a bit) would be enough to reduce emissions by 29 per cent.

IN DEFENCE OF CARNIVORES

As for veganism, it does seem to be edging ahead in the planet-saving stakes. Many of the issues that arise from farming livestock for meat – methane emissions from animal digestion, energy-intensive feeds – also apply to the dairy and egg industries. If widespread veganism was enacted, that 63 per cent reduction in emissions shoots up to 70 per cent.

These seem like hard figures to ignore, and yet ignored they are by the majority of people. While plant-based diets have now been normalised in a way that was probably unimaginable in Lappé's day, practising vegetarians and vegans are still relatively thin on the ground. It's thought only two per cent of the UK population is vegetarian, and less than one per cent is vegan.

But maybe cutting out animal products entirely, or nearly entirely, isn't necessarily the way to go. There have been studies published in reputable journals which suggest that vegetables may not be our sole salvation. Back in 2015, one paper caused a media firestorm when its lead author, Prof Paul Fischbeck of Carnegie Mellon University, made the declaration that

Problem Pallets
Workstation 7

"eating lettuce is over three times worse in greenhouse gas emissions than eating bacon". "LETTUCE WORSE THAN BACON" screamed the headlines, as commentators smugly observed that vegetarianism isn't all it's cracked up to be.

Other research has suggested that at least some degree of carnivory could be beneficial. A recent analysis of 10 diets, each with a different ratio of meat and animal products, saw veganism relegated to fifth position when it came to maximising sustainable land use, below different degrees of vegetarianism and omnivory. This comes as a blow to vegans who tend to assume that due to the well-documented problems with livestock farming, their diet plan automatically places them in the top spot.

ABOVE: **Shelves groan with food at a Tesco distribution plant in Reading**

RIGHT: **Modern Western diets still contain too much meat**

GETTY, SHUTTERSTOCK

How can researchers come to such different conclusions? Well, the short answer is because they're trying to answer a complicated question. To work out the best diet for the planet, scientists tally up the environmental costs of the production, transportation and marketing of foods, and then compare the options. Yet there are many such costs involved and therefore many potential metrics. Some researchers completely ignore certain aspects, such as the amount of food that's wasted, while others place more emphasis on aspects that they deem to be most relevant.

For example, there's no question that red meat produces far more emissions than vegetable protein sources such as lentils and beans – around 13 times more, in fact. But if you're focusing on land use, then cows and sheep start to make a lot of sense. Livestock, and food for livestock, can be farmed on land that's unsuitable for human crops, so if that land can be put to good use it will improve the efficiency of food production in a given area.

Recently, 'dumpster divers' have put food waste in the spotlight by salvaging edible food from skips

SAVING THE WORLD, ONE BITE AT A TIME

5 things to eat MORE of...

MUSSELS
These shellfish can be grown on ropes, causing minimal damage to the marine ecosystem. But they can also absorb carbon from the environment to grow their shells. What's more, being filter feeders they require no feed input whatsoever. They're full of fatty acids and vitamins too.

LEGUMES
Compared to other protein sources, legumes – beans, peas and lentils – require little water or fertiliser, and their carbon footprint is low. These plants even 'fix' nitrogen from the atmosphere into the soil, converting it into ammonia that other plants need to grow.

TILAPIA
These freshwater fish can be grown in closed tank systems, avoiding the water pollution usually associated with fish farms. As they are not carnivores like many commercial fish species, they don't need to be fed fishmeal, which means their diet doesn't deplete wild fish stocks.

SOFT CHEESE
Cheese generates the most greenhouse gases after red meat, which is something that non-vegan vegetarians ought to bear in mind. However, if you must eat it, opt for the softer varieties as they contain less milk, and tend to require less energy during the production phase.

LOCAL, SEASONAL FRUIT AND VEGETABLES
Yes, it can be somewhat limiting, but around 10 per cent of any food item's greenhouse gas emissions comes from its 'food miles'. You can limit those emissions if you buy produce that was grown across the street, rather than across the ocean.

As for the idea that lettuce is worse for the environment than bacon, the researchers had opted to analyse emissions on a per calorie basis. This seems an unfair comparison. After all, no one is suggesting that vegetarians replace two rashers of bacon at breakfast with the 3.3kg of lettuce it would take to match them, calorie-wise. But what Fischbeck and his colleagues wanted to emphasise was the need to consider foods on their individual merit, rather than assuming that just because you have chosen diet A or diet B, you're automatically saving the world.

VARIETY IS THE SPICE OF LIFE

This is a good point. There's an awful lot of variety in green credentials, even within food groups. Beef and lamb produce far more emissions than pork, which produces more than chicken. As for fish, the variation in impact is enormous, so diverse are the means by which different species are caught or farmed and the levels of threat they're all under in different parts of the world.

> Ultimately, the choices you make about your food are just as important as the diet tribe you belong to

Fruits and vegetables are even more complicated. Robust produce that can be grown in fields, such as cabbage and potatoes, result in relatively low greenhouse gas production, but if a plant requires intense refrigeration, or has to be grown in a hot house, alarm bells begin to ring. Similarly, vegetables that must be flown great distances before they arrive on your plate come with a sizeable emissions price tag. That's before you consider the huge quantities of water needed to grow citrus fruits or the pesticides that are pumped into banana plantations. Greenhouse gases, though the most widely used measure of impact, only tell one side of a complicated story, and those who opt for more plant-based diets must be wary of replacing the animal parts of their diet with plants that cause harm in other ways.

The fact is, whichever label you choose to define yourself and your diet by – vegan,

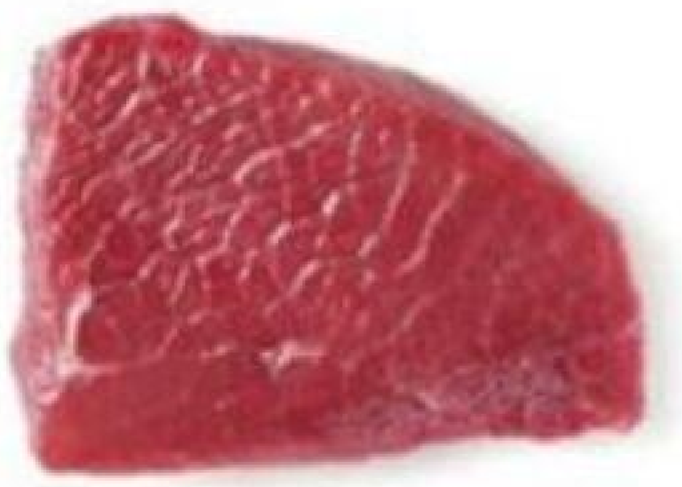
5 things to eat LESS of...

SUGAR
The huge quantities of sugar produced around the world have a significant environmental impact. Sugar cane is one of the world's thirstiest crops, and the conversion of sensitive habitats like Vietnam's Mekong Delta into sugar monoculture has seriously harmed biodiversity.

TUNA
It's possible to purchase 'ethical' tuna, but it's difficult to navigate the various species and fishing methods in order to ensure it's sustainably sourced. Skipjack is good, bluefin is bad. Pole-and-line is good, long line is bad. Your best bet is probably to stick to safer options if you fancy some fish.

AVOCADOS
Since avocados have become synonymous with a hip, healthy lifestyle, it's easy to forget that they are no friend to the planet. It takes around 272 litres of water to produce two or three avocados, and many of them are being grown in the drought-stricken farms of California.

SOY
Linked with everything from groundwater contamination to deforestation of the Amazon rainforest, soy is high up in the rankings of worst foods for the environment. But it's not the vegan munching on a soy burger who should feel bad – around 75 per cent of all soy is fed to livestock.



BEEF
While there are issues with farmed meat in general, beef is in a league of its own. One study estimated that beef requires 28 times as much land as the same amount of poultry and pork, as well as 11 times as much water and it produces five times as much greenhouse gases.

GETTY X11

vegetarian, pescetarian or omnivore – there's no room for complacency. Ultimately, the choices you make about your food, where it comes from and how it's made, are just as important as the diet tribe you belong to.

FUTURE FARMING

Another layer of complexity is the variety of farming strategies in use. Rather than demonising meat, some argue policies could ensure that livestock farming is more efficient and produces fewer greenhouse gases. This may sound too good to be true, but scientists have suggested that by simply supplementing the grazing diets of cattle and sheep with higher quality feeds, emissions from livestock farming could be reduced by nearly a quarter in the next two decades.

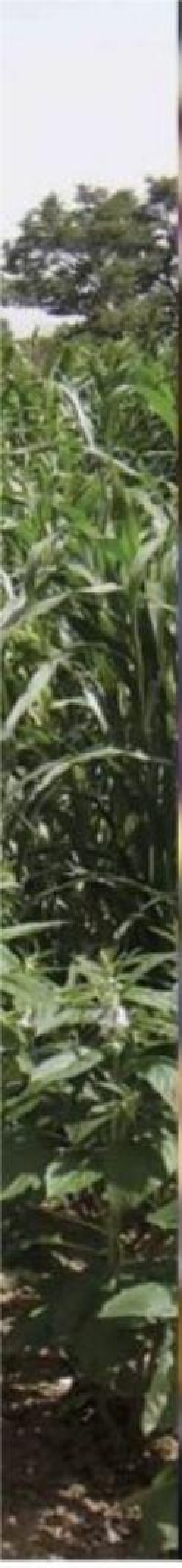
So relatively simple changes can make a difference, but when considering the scale of our food system's impact on the planet, something bigger might be necessary. Industrial agriculture has been our go-to system for some time, but the overuse of powerful chemical pesticides and fertilisers is resulting in degraded ecosystems that are unsustainable.

The solution to this could be agroecology, which operates under the mantra of 'working with nature, rather than against it', restoring biodiversity and ecosystem functions in order to ensure productivity. These principles are already being put into action. As it stands, rice accounts for up to a third of our annual water use, but a low-water agroecological method known as System of Rice Intensification is increasingly being used to produce rice yields up to 50 per cent larger. Water is only applied to the rice when needed, compost is used instead of chemical fertilisers and farmers weed by hand, instead of using herbicides. Using this method, Sumant Kumar, a farmer from the Indian state of Tamil Nadu, has smashed the previous annual rice-growing record by an astonishing three tonnes. Whether it involves rice, pigs, fish or apples, agroecology is about dismantling the current system and placing power into the hands of small-scale producers and family farms. If this sounds a bit too 'eco-warrior' for your taste, it's worth noting that even the UN is behind this trend. "Modern agriculture, which began in the 1950s, is more resource intensive, very fossil fuel dependent, using fertilisers, and based on massive production. This policy has to change," declared UN representative Prof Hilal Elver back in 2014, explaining that it is agroecology that holds the key to a sustainable future.

A truly environmentally friendly diet relies on major systemic changes, but individual diets also need to change

INCONVENIENT TRUTHS

A truly environmentally friendly diet relies on major systemic changes, but individual diets also need to change. The variety of data on offer can give the impression of flip-flopping within the scientific community, but it's more indicative of the sheer complexity of the subject – not to mention the competing interests of stakeholders in the food industry. In fact, certain trends are clear.



VEGETARIAN

ABOVE LEFT: Agroecology involves working with nature and putting control back in the hands of small-scale farmers

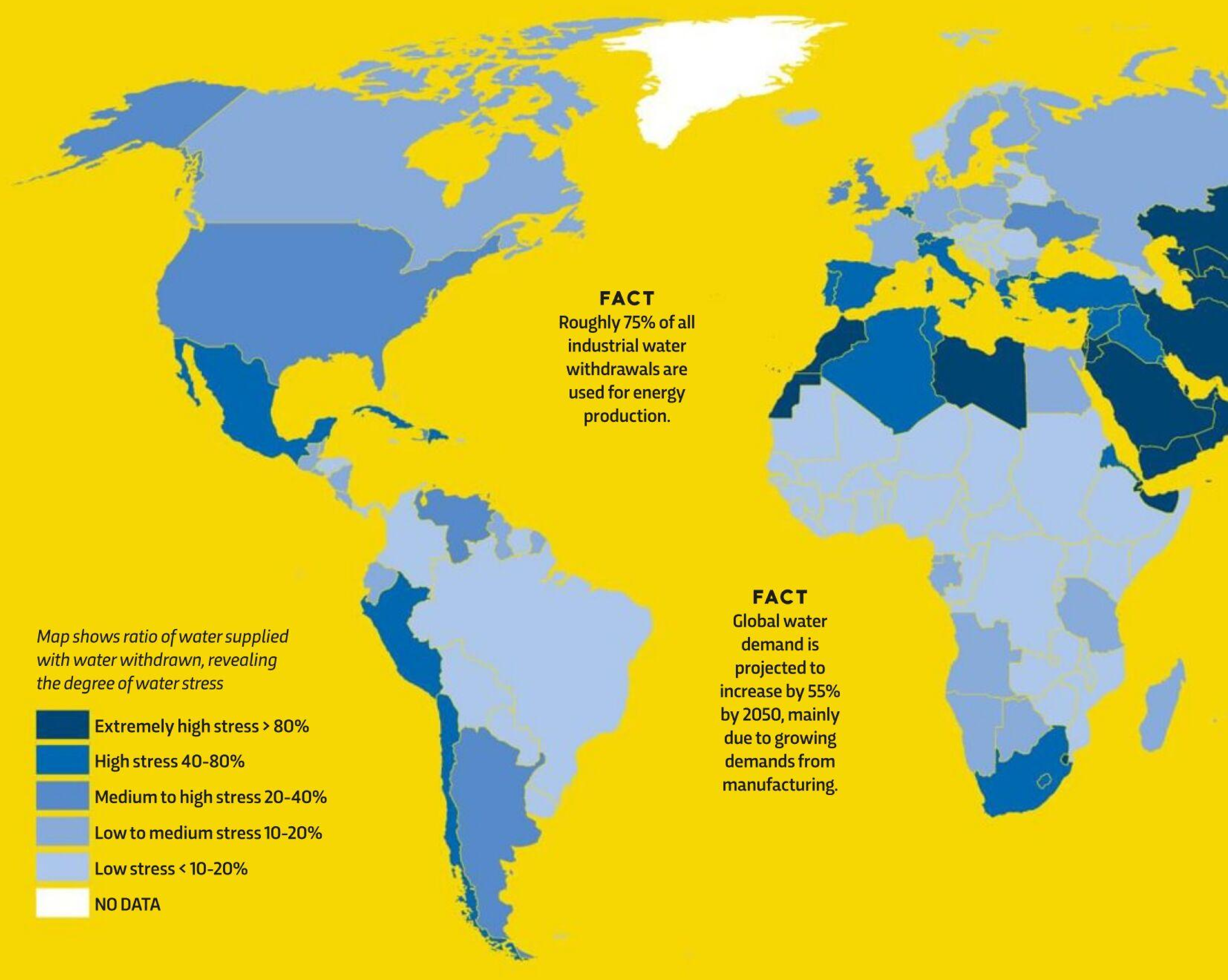
ABOVE: People who follow vegetarian diets should still be aware of how their favourite foods affect the planet

RIGHT: Red meats, like beef and lamb, have a greater impact on the planet than chicken

Headlines about the evils of lettuce and veganism saving the world may seem misleading, but it would be disingenuous to pretend that farming animals isn't a problem. People in the West are eating too much meat, and as countries like China and India become wealthier, their demand for it is increasing. Dr Rajendra Pachauri, ex-chairman of the UN's Intergovernmental Panel on Climate Change called for one meat-free day a week as a way of personally making a difference, and this seems like a good place to start. Other sensible suggestions include choosing fish from sustainable or certified stocks, buying vegetables that store well and avoiding food waste. The kind of mass switch to veganism envisaged by some studies is probably unrealistic, but relatively small changes in the way we eat can produce sizeable effects. We should be at a stage where suggestions like Pachauri's are not controversial because, while we may not have all the information, we certainly have enough to make a difference.

Josh Gabbatiss is a science writer based in London. He tweets from @Josh_Gabbatiss.

GETTY X2, AGROECOLOGY FUND


Extremely high stress > 80%
High stress 40-80%
Medium to high stress 20-40%
Low to medium stress 10-20%
Low stress < 10-20%
NO DATA

Map shows ratio of water supplied with water withdrawn, revealing the degree of water stress

FACT
Roughly 75% of all industrial water withdrawals are used for energy production.

FACT
Global water demand is projected to increase by 55% by 2050, mainly due to growing demands from manufacturing.

HOW TO KEEP THE

Water stress can quickly turn into a water war. So how can we reduce our usage to keep the peace and protect the planet?

A person can survive without food for a number of days, but dehydration can quickly kill them. Hence, water is our most precious resource. But it is becoming increasingly scarce, due to climate change and a rising demand from an exploding population. Most water is actually used for irrigation, rather than for drinking or around the home. Indeed, agriculture accounts for 70 per cent of global water withdrawal. The Middle East and North Africa only have 1.4 per cent of the world's fresh water resources, yet 6.3 per cent of the global population. In the US, the average person uses 445 litres a day – 60 per cent for flushing

FACT
1kg of rice takes 3,000-5,000 litres of water to produce (2,000 litres for 1kg of soya, 900 litres for 1kg of wheat and 500 litres for 1kg of potatoes).

FACT
Ground water supplies are rapidly disappearing. An estimated 20% of the world's aquifers are being over-exploited.

TAP ON

toilets, having a bath, washing clothes and so on, 30 per cent for watering the garden, and 10 per cent is lost through leaks.

But some people are turning to technology. In agriculture, researchers are developing drought-resistant crops, and employing methods such as capturing rainwater and drip irrigation. In the home, simple measures can reduce usage, like water-efficient washing machines and dishwashers, and changing to low-flow taps and showerheads. Simply switching to low-flow devices would cut heating costs and hence carbon emissions by 4.6 gigatons by 2050.

FOGQUEST/PABLO OSSES. SOURCES: DRAWDOWN (PENGUIN, 2017), NEW VIEWS/ALASTAIR BONNETT, UNITED NATIONS

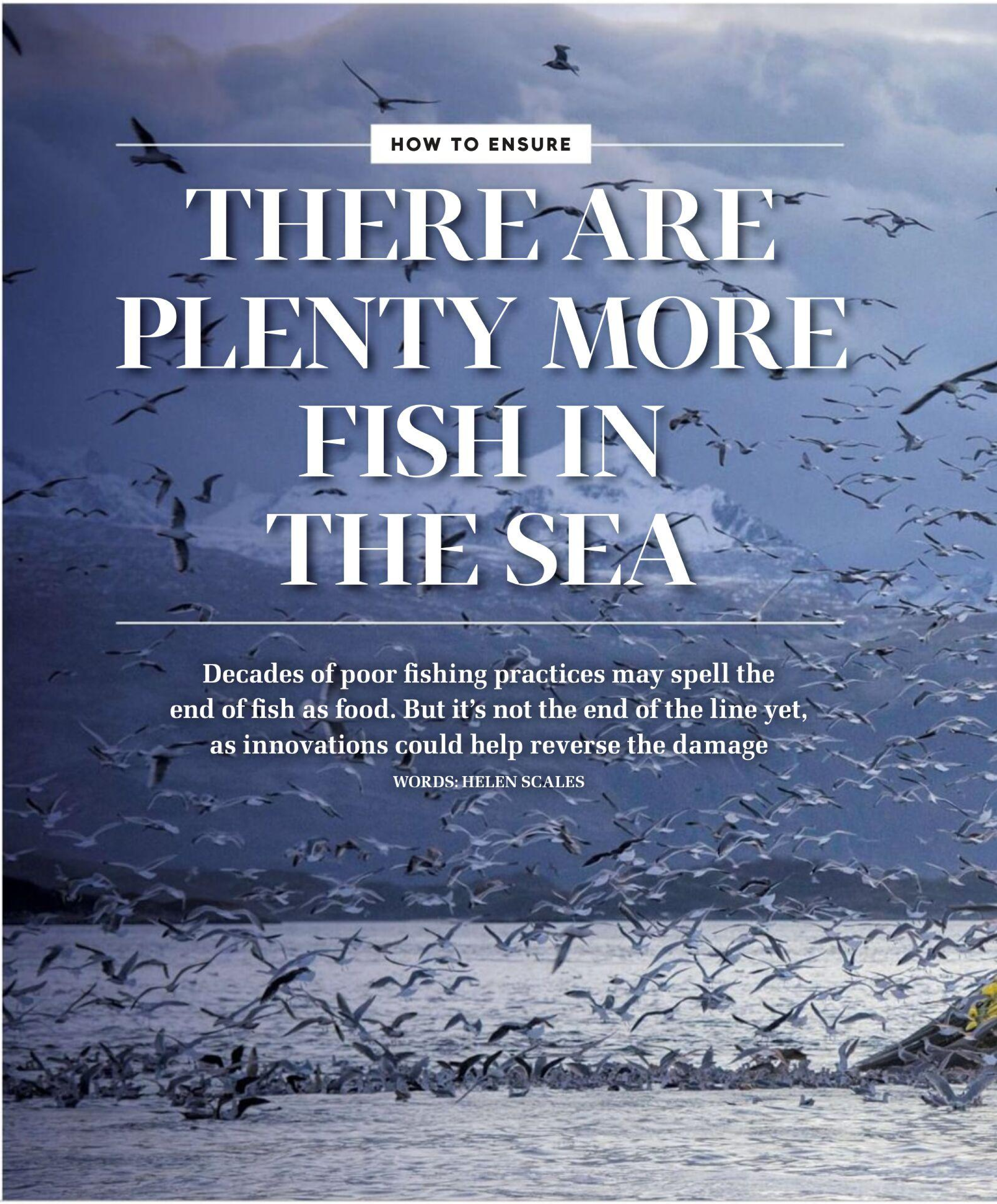
CLEVER WAYS TO HARVEST AND STORE WATER

FOG COLLECTORS

Even in the driest parts of the world, fog offers a source of clean water – provided it can be collected. Using a cheap commercial mesh designed for shading plants, scientists at FogQuest have created 'fog collectors' that can trap an average of five litres of water per square metre of mesh per day. The wind pushes the tiny fog droplets against the mesh, and then gravity pulls the big droplets down, moving the water through connected pipes to a cistern. Since 2000, FogQuest has helped to set up projects in arid environments all over the world, from the Atacama Desert in Chile to the Everest region in Nepal.

MANMADE GLACIERS

Water is in short supply in the Himalayan desert during spring – a problem that the Ice Stupa Project, launched in 2014, aims to solve by growing glaciers from scratch. The technology is surprisingly simple. One end of a pipe is placed upstream and the other end downstream where it jets out in a fountain. In the cold air on the Tibetan plateau, this water freezes as it falls. Over time, ice builds up from the ground, creating conical towers that Wangchuk calls 'stupas' because of their resemblance to the Buddhist structures of the same name.



HOW TO ENSURE

THERE ARE PLENTY MORE FISH IN THE SEA

Decades of poor fishing practices may spell the end of fish as food. But it's not the end of the line yet, as innovations could help reverse the damage

WORDS: HELEN SCALES

GETTY

TRIPLEX
N TRØM

> From the survey emerged a headline-grabbing forecast: by 2048, all existing fish stocks could have collapsed

A reef shark slides past, an arm's length away, then another. These sleek hunters pay me no attention and seem accustomed to having people nearby. Scuba divers flock to visit the marine life flourishing around the remote islands of Palau in the Pacific Ocean. This special place offers a glimpse of how things used to be before human activities began emptying the oceans.

Palau remains a rare underwater wonderland, in part because the government takes marine protection seriously. A whopping 80 per cent of the nation's waters are off limits to fishing. This is one of a new generation of marine reserves. In August 2016, Barack Obama announced a huge expansion of Hawaii's Papahānaumokuākea marine reserve. It's the biggest yet, a massive 1.5 million square kilometres – around the size of Spain, France and Germany combined.

In 2006, a prominent group of marine scientists published a paper in the journal *Science* scrutinising the state of the oceans around the world. From their survey of the abundance and diversity of marine life emerged a headline-grabbing forecast: by 2048, all existing fish stocks could have collapsed.

Not all experts agreed on that date, which assumes the present rate of collapse will continue at its current rate – already a third of all fish stocks have collapsed since 1950. Others have re-analysed the same data and pushed the date forwards to the 2100s. Still, it's a dire prognosis for fisheries that feed billions.

Fishing lines and nets lost at sea do not readily break down, so they can continue trapping animals for years

JORDI CHIAS/NATUREPL.COM

In 2016, a major study, published by marine biologist Dr Daniel Pauly and colleagues from The Sea Around Us project, warned that the world has probably already passed 'peak fish'.

Behind the global fishing crisis lies a catalogue of problems. First and foremost, there are simply too many fishing boats chasing fewer and fewer fish. This is partly because of financial subsidies and other perks keeping fisheries afloat.

Fishing also physically damages the marine environment. Trawlers and dredgers scrape heavy nets across the seabed, smashing delicate, centuries-old habitats. Huge quantities of unwanted sea life are caught that have no market – and then this bycatch is thrown straight back into the sea, already dead or dying.

Added to all this are convoluted impacts of pollution and climate change. Warming seas are driving certain species towards the poles, rearranging ecosystems and causing coral reefs to bleach and die, while carbon emissions are making oceans more acidic, which weakens shellfish and alters fishes' hearing and behaviour. To make matters worse, fish that end up on our plates are also becoming filled with fragmented plastic. Nevertheless, effective solutions are already available.

SAVING THE SEAS

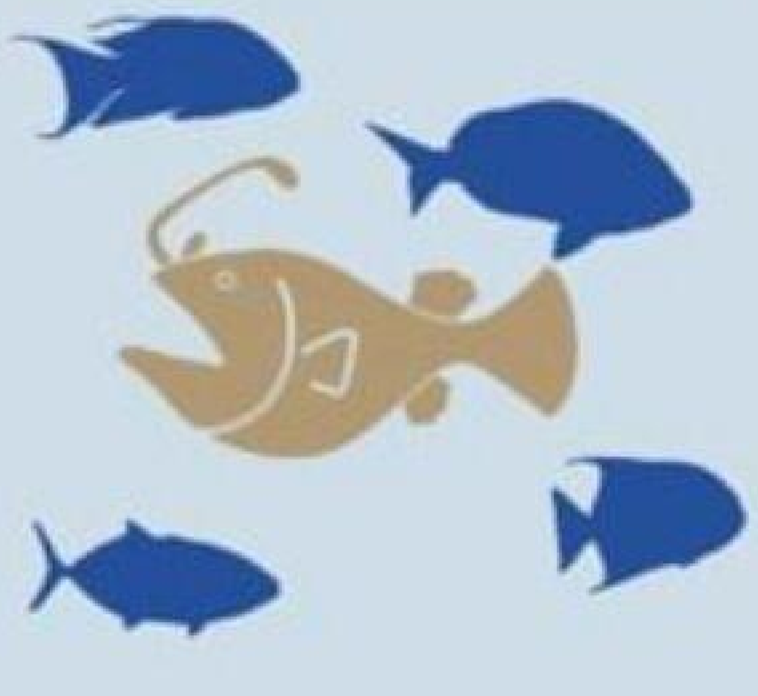
Marine reserves are a proven way of restoring fish populations. By excluding fishing from particular areas, reserves allow marine species to recover from previous exploitation.

A 2009 study showed reserves dramatically boost the density of marine species, by 166 per cent on average; species diversity also goes up by around 20 per cent. Reserves also keep habitats healthy and make ecosystems more resilient to climate change. A well-known example comes from the Philippines. In the 1980s, 10 per cent of the coral reefs around ➜

THE STATE OF OUR SEAS

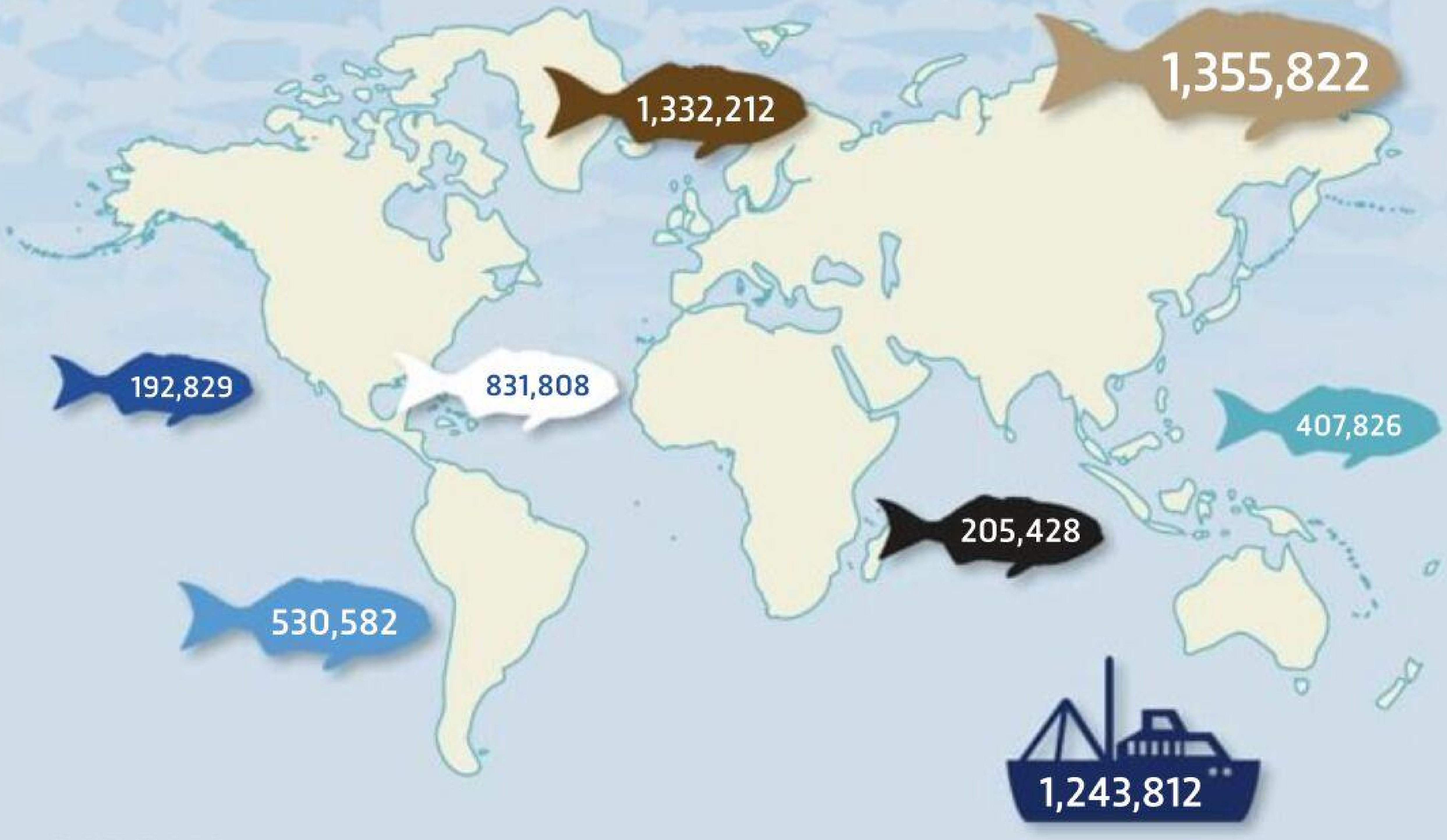
OVER 2.5

billion people rely on fish for a major source of protein



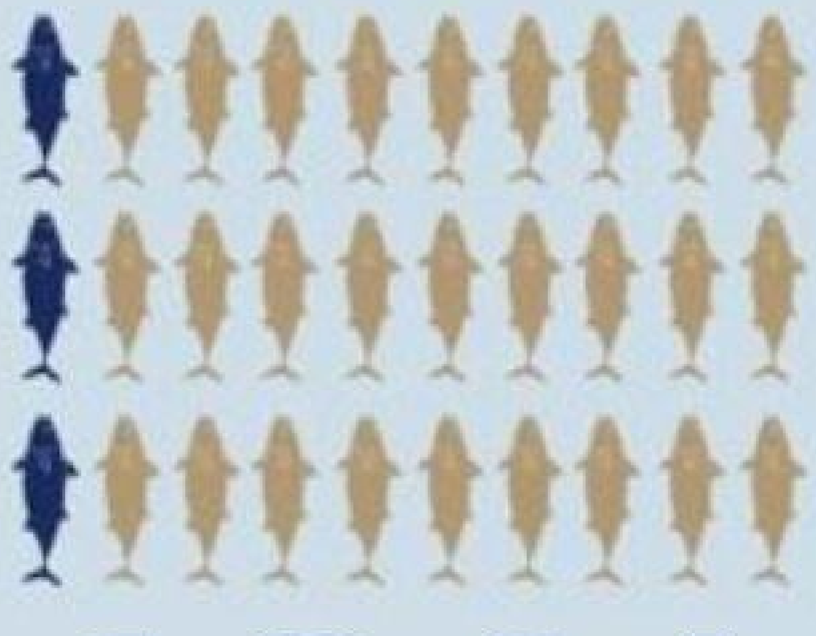
ONE IN FIVE FISH IS CAUGHT ILLEGALLY

Every day, the amount of longlines set out in the oceans would wrap around the globe 500 times



ANNUAL DISCARD RATE (IN TONNES) BY OCEAN REGION

- NORTHEAST PACIFIC
- SOUTHEAST PACIFIC
- NORTHEAST ATLANTIC
- WEST CENTRAL ATLANTIC
- NORTHWEST PACIFIC
- WEST INDIAN OCEAN
- WEST CENTRAL PACIFIC
- REST OF THE WORLD



10%

of the global fish catch is certified as sustainable by the Marine Stewardship Council

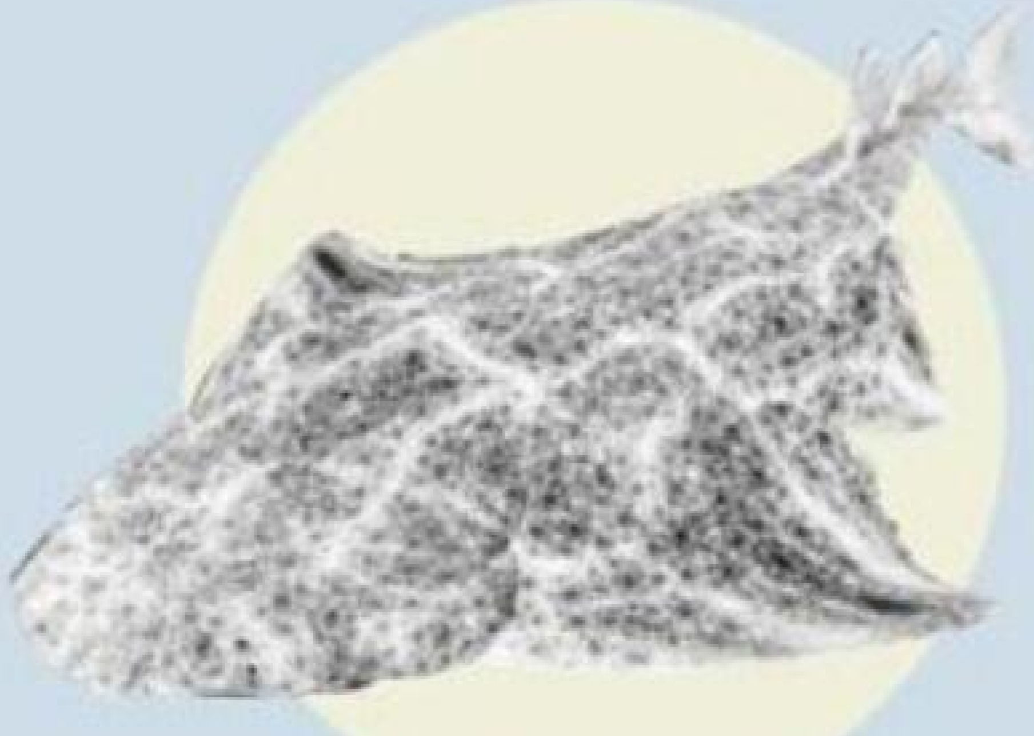
Plastic waste in the oceans could outweigh the fish by 2050

FISH STOCKS

could be declining three times faster than official figures suggest

THE BIGGEST LOSERS

Some species are more sensitive to pollution and fishing than others…



ANGEL SHARK

The angel shark was once common from the North Sea to the Mediterranean. As it lives on the seabed, it is taken as bycatch by trawlers and has been almost completely wiped out. Now it only lives around the Canary Islands.

TOTOABA

Illegal fishing is driving the totoaba to extinction in its native range in the Gulf of California. Its swim bladder, an organ that regulates buoyancy, is worth up to £6,500 a piece in China to make into soup.

WHALE SHARKS

In 2016, the whale shark was listed as endangered by the World Conservation Union because its numbers have halved in the last 75 years. It only becomes sexually mature at between 20 and 30 years old, so populations take a long time to recover.

COMMON SKATE

With a name that's become sadly ironic, the common skate is critically endangered in the Atlantic and Mediterranean, and extinct in the Baltic. Along with some other skate species, its large size makes it vulnerable to being caught in nets.

EUROPEAN EELS

Numbers of young European eels have crashed by up to 95 per cent in the last 30 years. Declines are blamed on habitat loss, pollution and barriers to migration. Eels are born in the Sargasso Sea, before migrating across the Atlantic and up into rivers and streams, where they mature.

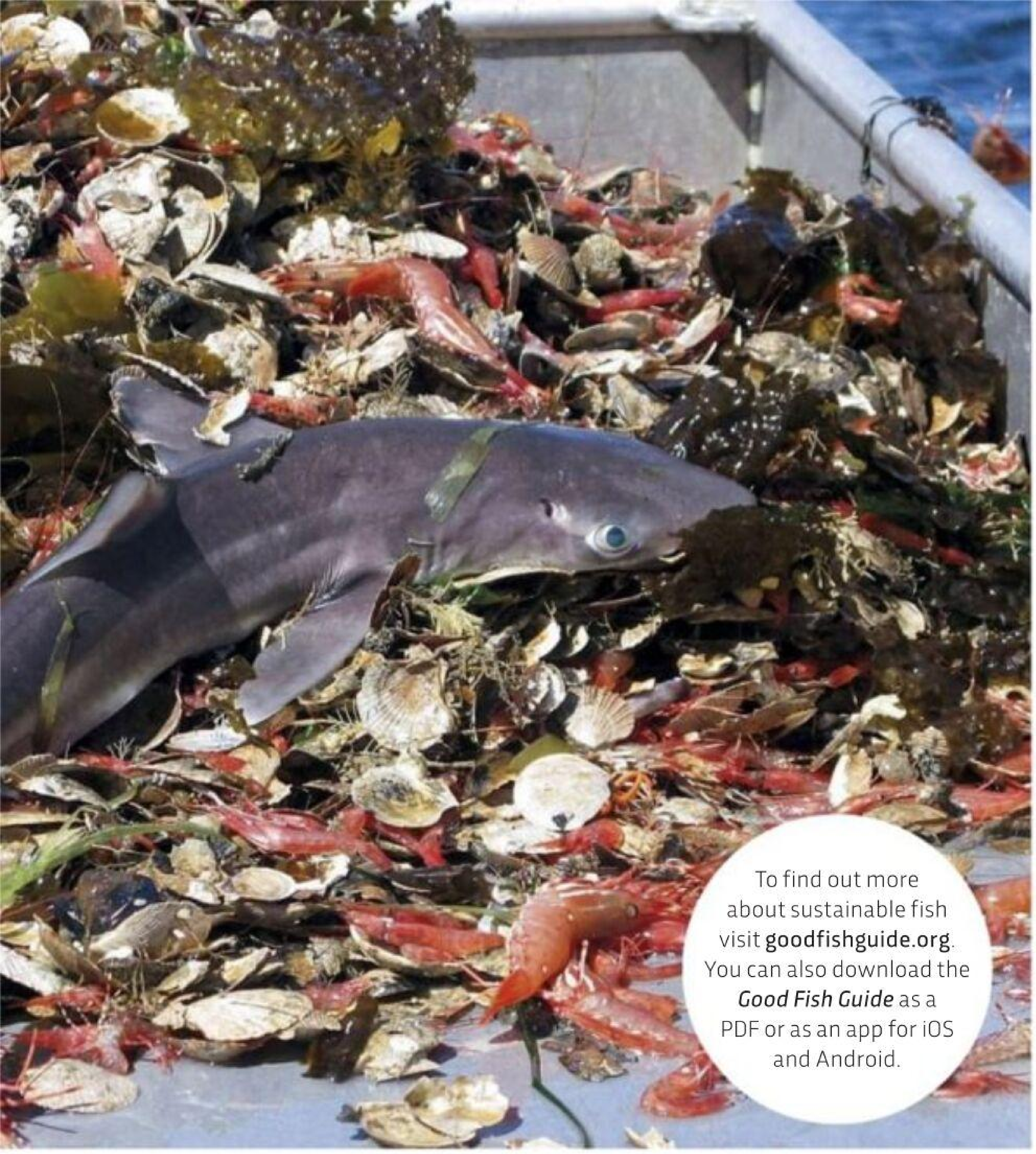
Certain fishing methods indiscriminately plunder the seas, sometimes catching vulnerable species, such as sharks, dolphins and turtles

Apo Island were closed to fishing. Twenty years later, the total quantity of the two main targeted fish groups had tripled inside the reserve. Benefits also spill out as adult fish and larvae move into unprotected areas, replenishing the wider seascape. The fishermen of Apo saw a 50 per cent increase in their catches outside the reserve.

A major obstacle, though, is enforcement. Many countries lack resources for patrols, especially in very large, remote reserves.

Global Fishing Watch is a free online tool showing where fishing is happening anywhere in the world. The project uses data from Automated Information Systems (AIS) required on many watercraft over a certain size to avoid them crashing into each other. Their data is being mined to detect which vessels are fishing, where and when. Google was brought to the party, to help analyse the big data generated by AIS devices and detect the characteristic movements of fishing. The Global Fishing Watch website currently tracks over 35,000 fishing vessels in near real-time;

ALAMY, GETTY X3, RICHARD HERRMANN/FLPA, SOLVIN ZANKL/NATUREPL.COM



To find out more about sustainable fish visit **goodfishguide.org**. You can also download the ***Good Fish Guide*** as a PDF or as an app for iOS and Android.

> “Consumer campaigns have made a big difference to the way supermarkets think about sourcing fish”

typically data go online around 72 hours from the present. It’s hoped governments will use the website to enforce sustainable fisheries regulations, such as closed seasons and marine reserves. Kiribati, a small nation located in the Pacific Ocean, has already used the data to fine a commercial vessel $1m for illegally fishing inside the Phoenix Islands Protected Area.

Technology is also being applied to deal with bycatch. The conservation group WWF runs Smart Gear, a competition to develop new ways to stop unwanted species being caught. Winners in 2014 included Super Polyshark. These pellets of slow-release non-toxic, biodegradable shark repellent are inserted in the bait that’s used on longline hooks. Tests show they reduce the number of sharks that go for the bait and get snagged. Other devices include scarers to reduce seabird deaths, and trapdoors in trawl nets that let turtles and cetaceans escape.

Back in Palau, studies are underway to limit bycatch in the 20 per cent of their national waters where fishing continues. The Nature Conservancy is testing different types of hooks in tuna longline fishing to reduce the bycatch of sharks and turtles, species highly valued by divers. Every living shark in Palau is worth up to $2m a year to the dive industry.

BUYING WISELY

Seeing supermarket shelves still stocked with seafood, it can be difficult to make sense of reports of emptying seas. It’s true that management successes have allowed some collapsed stocks to recover. In the 1970s, North Sea stocks of herring dramatically collapsed. “After a moratorium on fishing, together with some excellent management approaches, they’ve rebuilt the stocks,” says Prof Callum Roberts, a marine conservationist from the University of York. However, seafood supplies today are largely maintained by fishing in distant waters. Imports account for 90 per cent of seafood eaten in the US and around 60 per cent in Europe. This puts mounting pressure on other regions like West Africa, where there is little supervision to prevent overfishing and habitat loss.

This widening gap between plate and ocean makes it more important than ever for us all to care about where our seafood comes from. More seafood is being certified as sustainable through eco-labelling schemes.

“Consumer campaigns have made a big difference to the way supermarkets think about sourcing fish,” says Roberts. “The more shoppers say that this matters to me, the more likely it is that supermarkets will take note.”

Dr Helen Scales (@helenscales) is a marine biologist, writer and broadcaster. Her next book, *Eye Of The Shoal*, is out in May 2018.

BBC ONE

Watch clips from the landmark BBC One series *Blue Planet II*
bbc.in/2FvKwgf

Marathon

THE PLANT WHISPERER

*A **famine** crisis is looming. **Stephen Long's** work aims to feed the masses by supercharging the plants we eat*

In the mid 20th century, many parts of the world were on the brink of famine. A growing global population was butting up against the limits of food supply, with disastrous consequences. But the lives of more than a billion people were saved by a 'Green Revolution', in which techniques such as irrigation, and technologies including hybridised seeds, and human-made fertilisers and pesticides spread from industrialised countries to the developing world.

Today, we're facing a similar crisis. "The UN Food and Agriculture Organization says that we're going to need 70 per cent more food by 2050, and with current rates of crop improvement we're not going to get there," says Stephen Long, director of the RIPE Project, which aims to spur a second Green Revolution by engineering crops that photosynthesise more efficiently.

> "The UN Food and Agriculture Organization says that we're going to need 70 per cent more food by 2050. With current rates of crop improvement we're not going to get there"

"Photosynthesis is the process that converts sunlight and carbon dioxide into the substance of a plant, so it's basically the source of all of our food. We know that in crop plants this process isn't very efficient, and we now understand enough about the process that we can start to intervene and genetically improve its efficiency."

Prevailing wisdom would have it that photosynthesis can't be made more efficient. After all, why would evolution not have optimised such an important process? But Long points out that evolution optimises for survival and reproduction, not maximum output of produce.

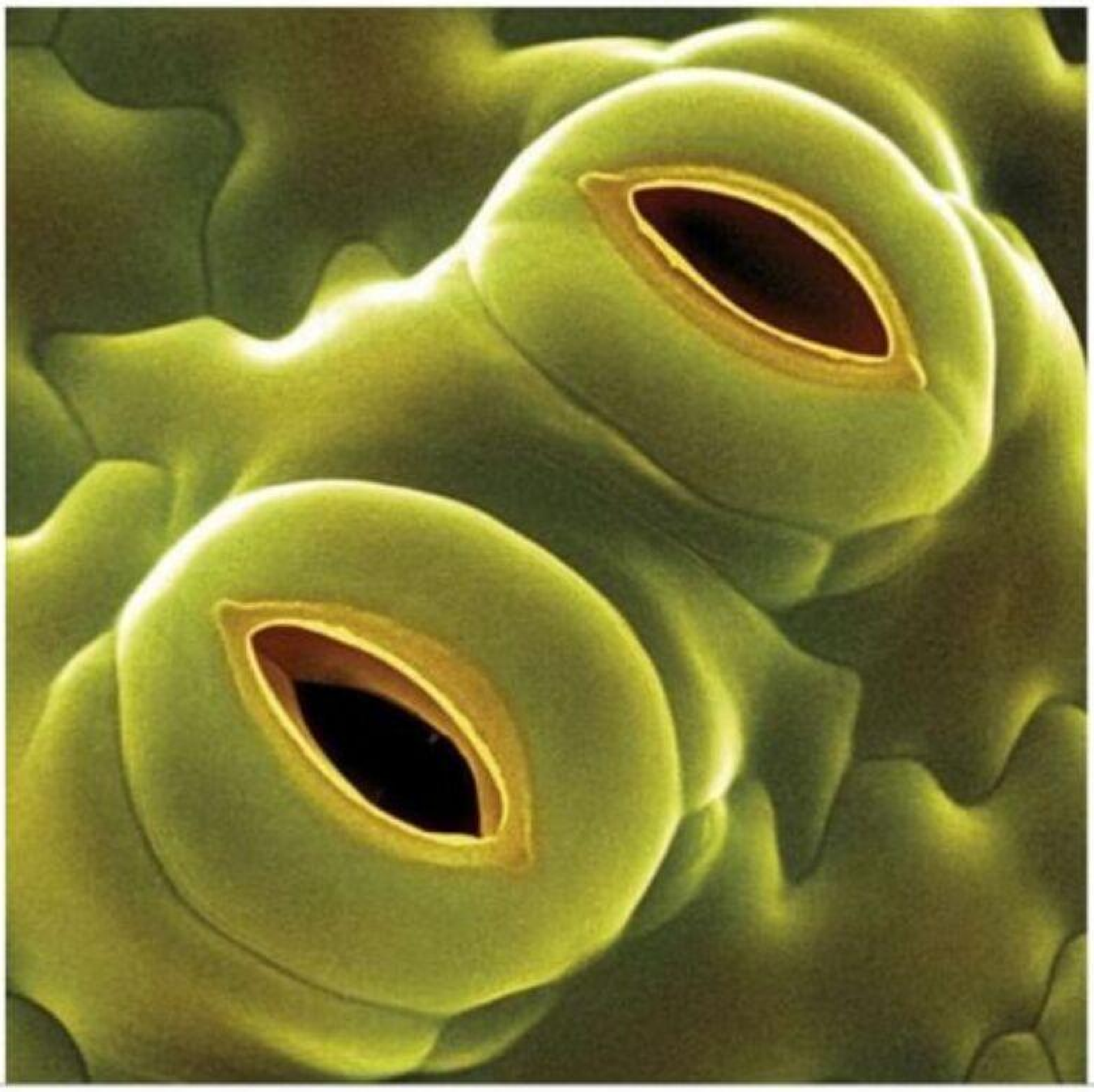
Also, the environment has changed since the first Green Revolution. "A major molecule involved in photosynthesis is carbon dioxide and in the last 50 years we've increased the concentration of carbon dioxide in the atmosphere by 25 per cent. That is a very short time for evolution to adapt to a change," says Long.

So, he and his team set to work proving that it's possible to boost the efficiency of photosynthesis. With funding from the Bill and Melinda Gates Foundation, they started tinkering with tobacco – a plant that's relatively easy to engineer. They transferred genes from *Arabidopsis thaliana*, better known as thale cress, to the tobacco plant in the hope of helping it shed heat energy more efficiently. When three variants of these engineered plants were grown, their yields were 13.5, 19 and 20 per cent greater than normal tobacco plants. "Although we understand photosynthesis now in detail, it is a complex process with over 160 discrete steps. The first part of the project was simulating the whole thing on a computer. We could then try billions of manipulations to find the best places to intervene."

What's more, these impressive gains were achieved with minimal increases in resource costs. The engineered plants required about 1 to 2 per cent more nitrogen than the unmodified plants, and no increase in water.

The big question is whether these gains in tobacco can be transferred to food crops, and there's reason to believe that they can. Photosynthesis works in the same way in tobacco as it does in many food crops, and tests are planned to see if similar modifications can deliver increases in yields of staples such as rice, cowpeas and cassava. The potential is huge, but the clock's ticking. "Any innovation we have today is going to take about 20 years to become available to farmers at the scale we need," says Long. "So while 2050 might sound a long way off, it's really quite close."

THE RIPE PROJECT ILLUSTRATION: MARIO WAGNER



ABOVE: Engineered seedlings are transplanted into a field as part of the RIPE Project

LEFT: A stoma on a tobacco leaf. These tiny pores regulate the exchange of gases between the atmosphere and a leaf's interior. When it's dark or during times of drought, they close up so the plants don't lose water

Q&A

What keeps you feeling optimistic?
Last year the first of these manipulations gave us a 20 per cent boost in productivity. Breeders are usually happy if they can get one per cent. So that really showed that we were onto something. This year, two of my colleagues working on different ways of improving photosynthesis had major successes in their field trials.

Have you ever had moments when you felt like giving up?
I've certainly had moments where I've felt like giving up. For a long time, there was a very strong belief that the process of photosynthesis couldn't be improved in crops because evolution couldn't possibly have left a free lunch on the table.

What's your response to people who say your project won't work?
My response is that we now have very strong evidence from replicated field trials that it is working.

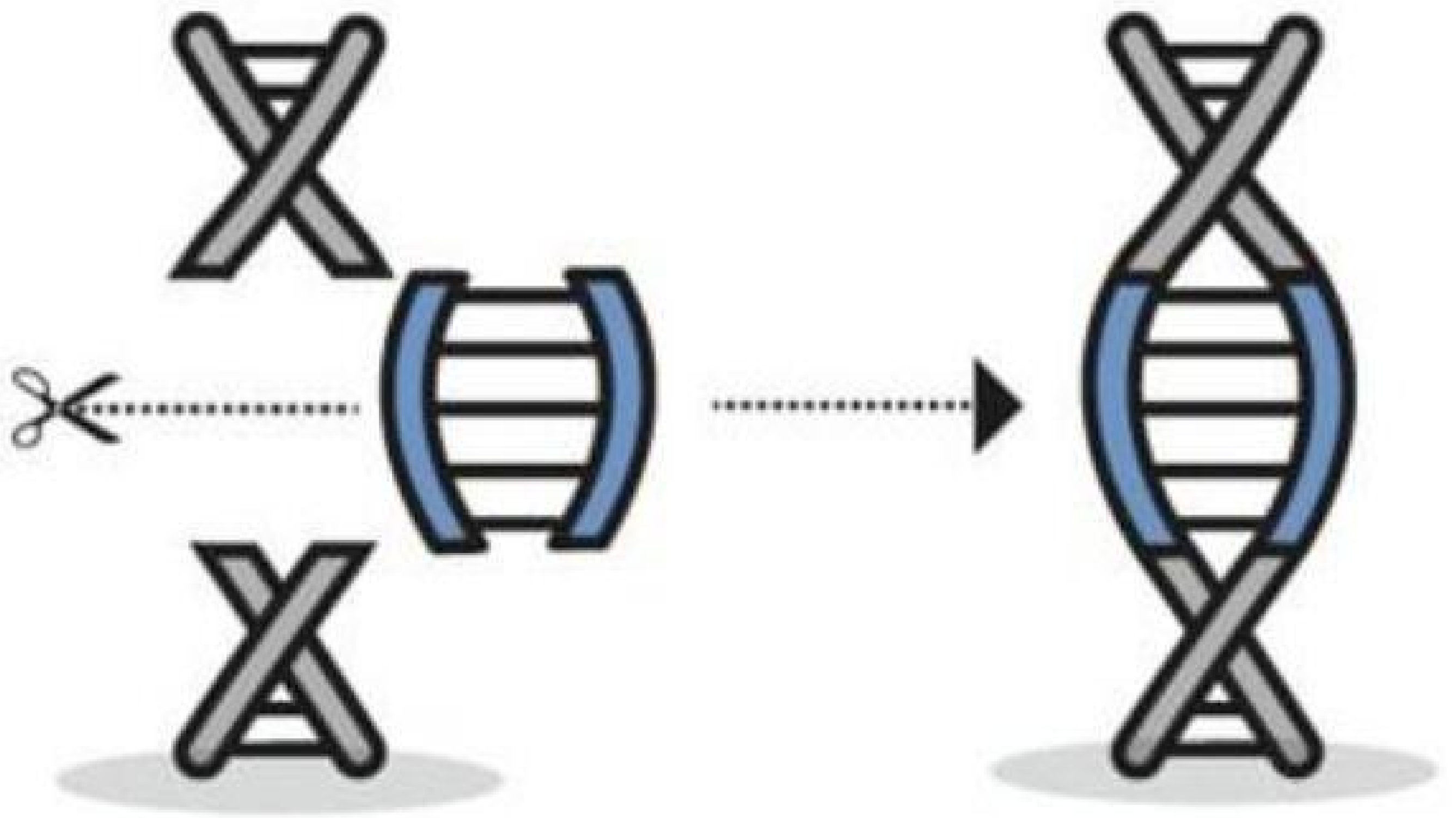
If you were able to rent out a billboard in Times Square, what would you write on it?
'Don't be complacent about our global food supply – it's at serious risk.'

What will your field of research look like in the year 2050?
I think the genetic tools that have been developed over the last 20 to 30 years will be being deployed at scale. So, we'll have smart crops able to deal with different environments, and be far more sustainable. That's what the technology is going to allow us. Whether we accept that technology is going to be another issue.

HOW IT WORKS

TURBOCHARGING PHOTOSYNTHESIS

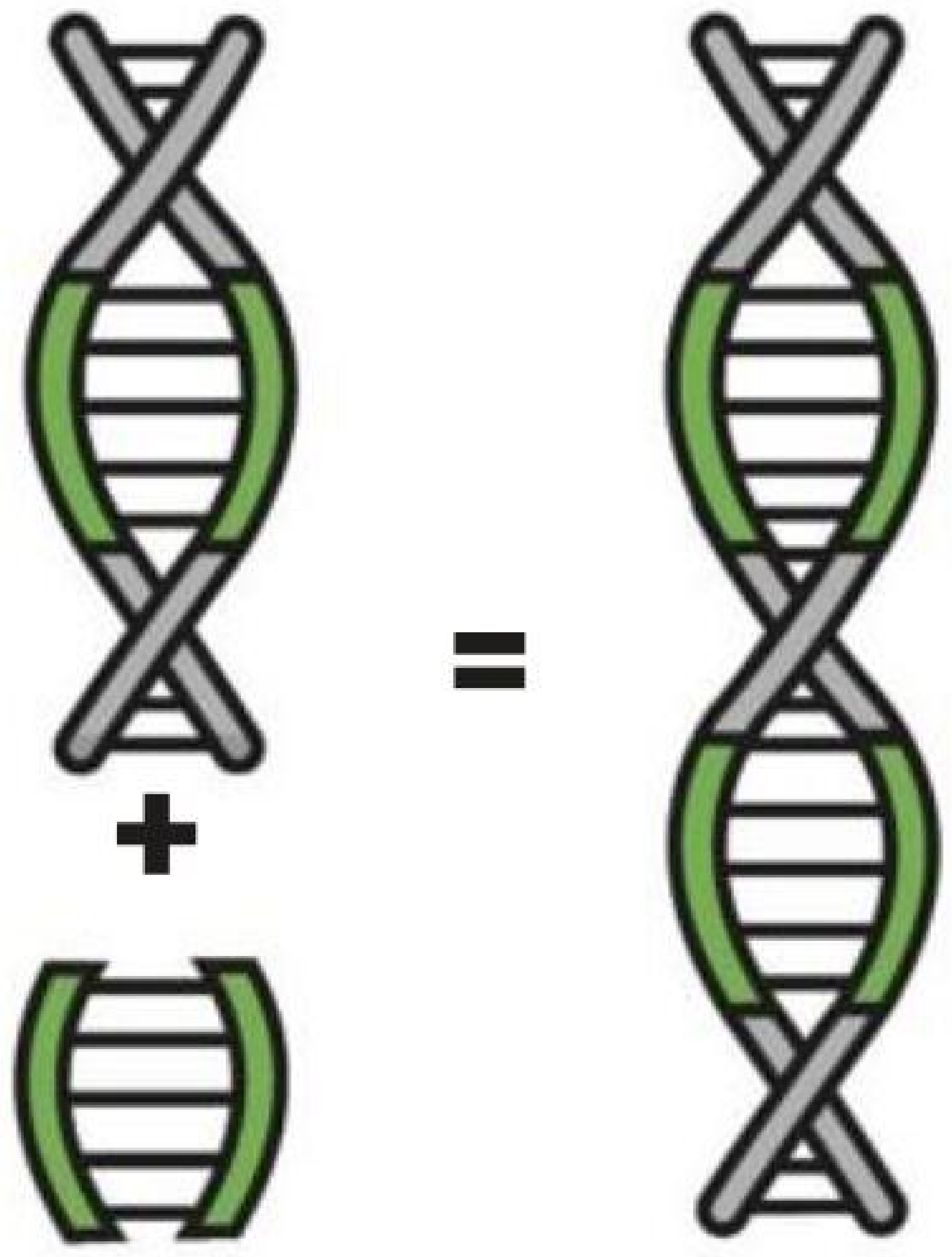
All plant cells have DNA, which contains genetic material. There are three ways that genes are being used to increase yields of crops.



METHOD 1

① A specific gene that can improve metabolic pathways is snipped out from another organism (blue).

② The gene is inserted into the plant's DNA, so the plant will become more efficient.

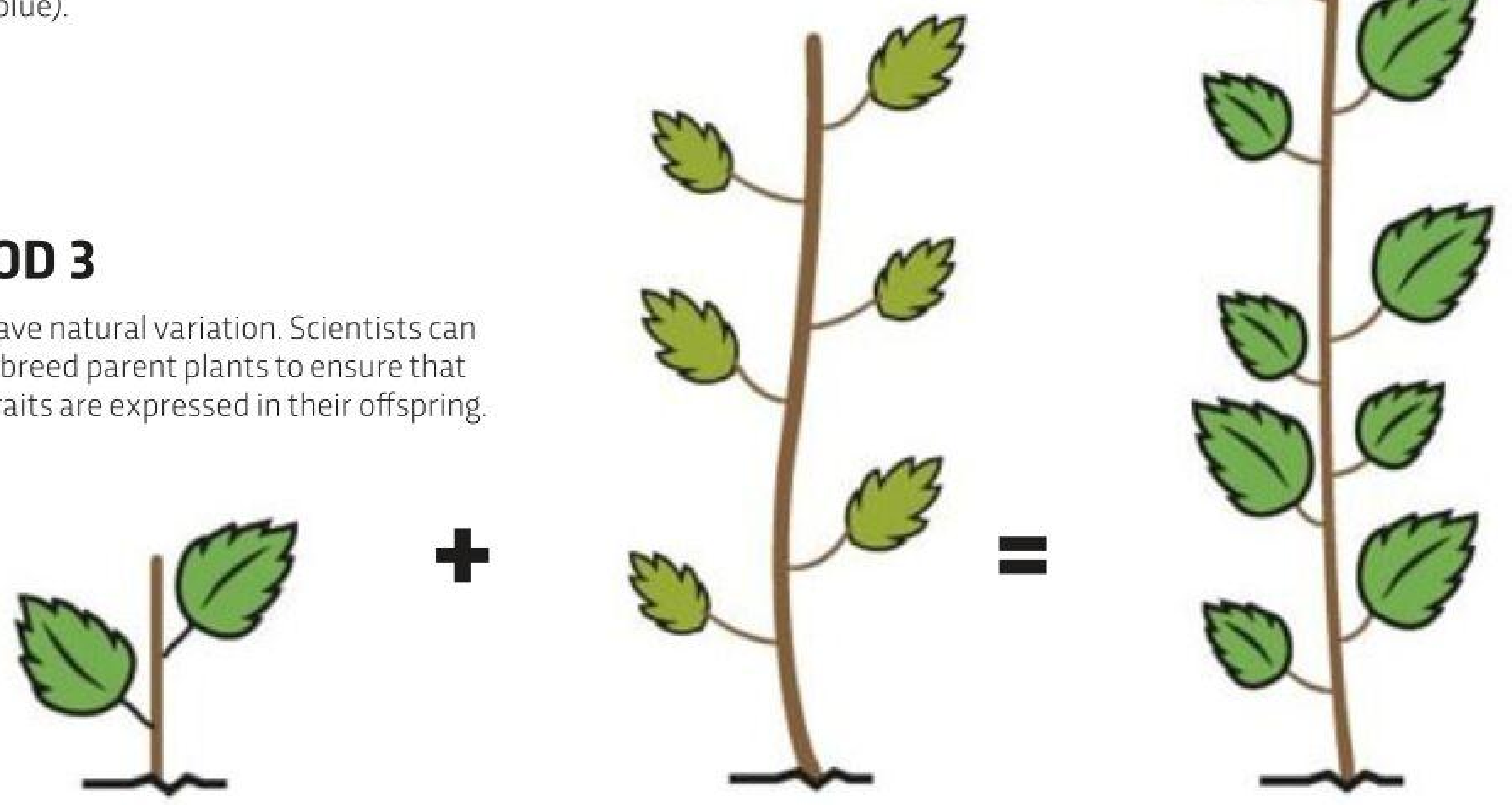


METHOD 2

① If a plant already has a particular desirable gene, then extra copies of the gene can be added to the plant's DNA to improve it even further.

METHOD 3

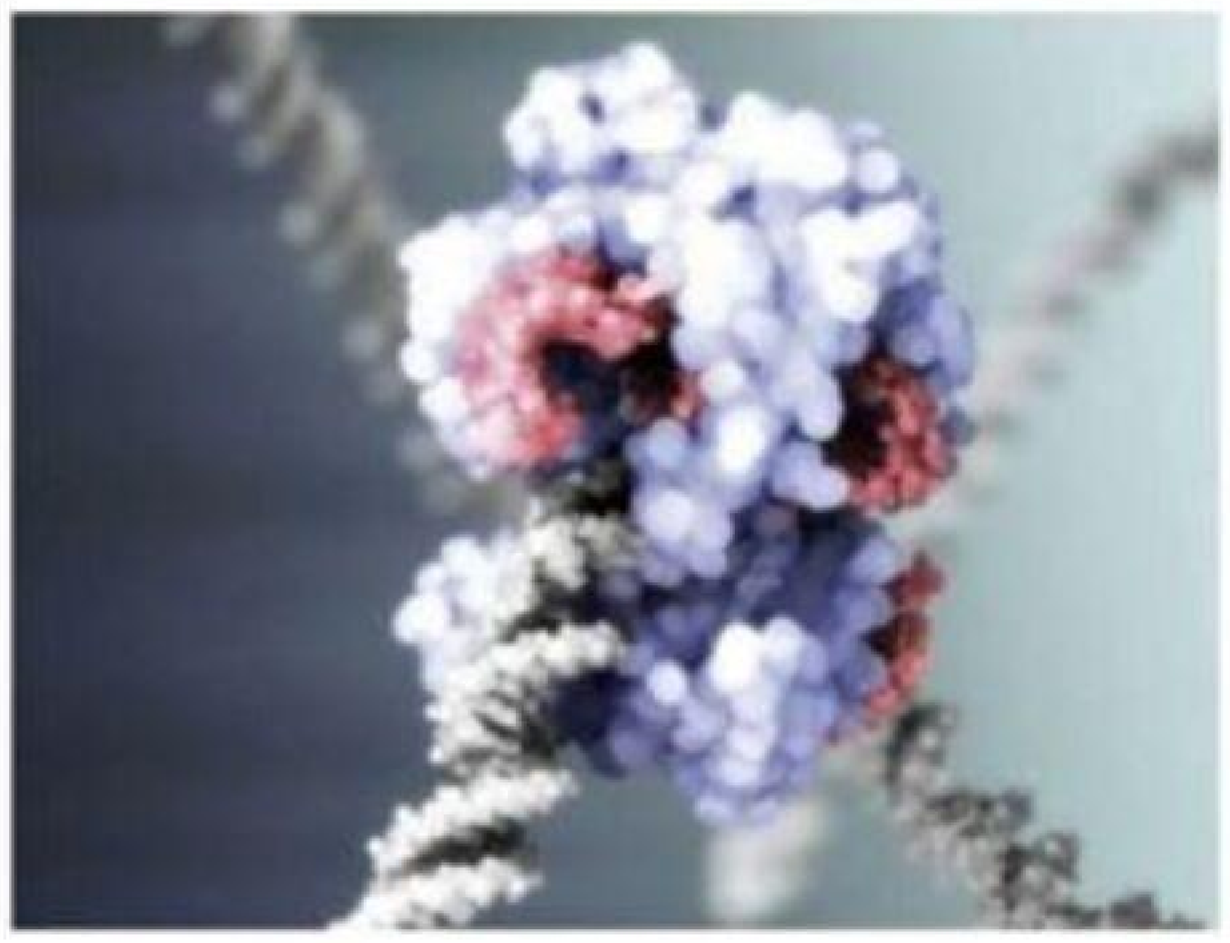
① Crops have natural variation. Scientists can selectively breed parent plants to ensure that desirable traits are expressed in their offspring.



FAMINE FIGHTERS

ZYGO BEETLE

In South Africa, farmers have learned to fear the plant *Parthenium hysterophorus*. It uses natural herbicides to prevent other plants growing near it, which causes havoc in farmers' fields. But since 2003, the country has been employing the weed's natural enemy – the Zygo beetle – to reduce its spread. Researchers at Wits University hope the beetle can establish itself to curb the weed's growth.



CRISPR/Cas9

Since the discovery of CRISPR/Cas9, a powerful tool for genetic editing, researchers have started using it to boost crop yields. Geneticists at the Chinese Academy of Sciences, have found a way to restructure wheat genes to make the crops immune to powdery mildew, while researchers at King Abdullah University of Science and Technology gave tomatoes immunity against the yellow leaf curl virus.

SATELLITE DATA

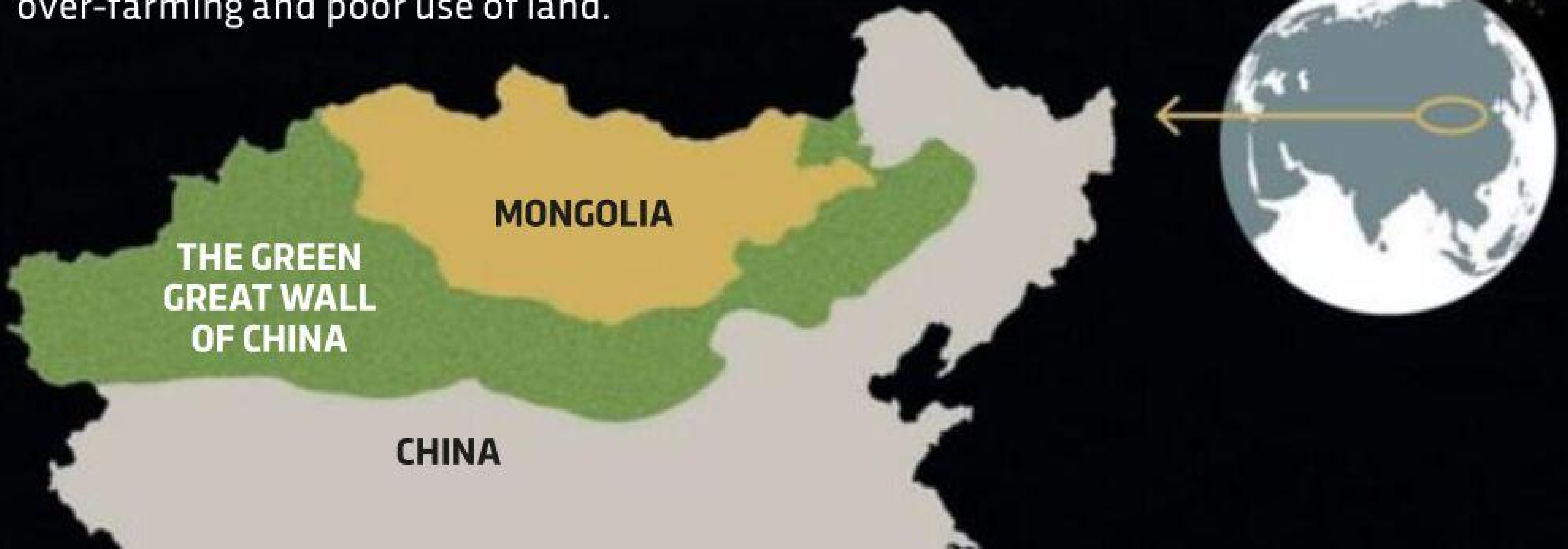
It's far easier to fight a famine when you know that it's coming, so a team from the US Geological Survey has designed a system that uses satellite data to detect the unusual spikes in land temperature that often cause crop failure. During its testing phase in Ethiopia, the project increased lead time by several weeks allowing action to be taken to prevent families going hungry and animals dying.

THE RIPE PROJECT, SCIENCE PHOTO LIBRARY X2, GETTY X2 ILLUSTRATION: ACUTE GRAPHICS

THE GREEN GREAT WALL

The Three-North Shelterbelt Program, aka the ‘Green Great Wall’, was launched in 1978 to halt the creeping advance of the Gobi Desert into northern China. Not to be confused with the Great Green Wall, a similar initiative planned for the Sahara, the project’s intention is to plant a belt of trees that will block the path of wind and dust storms from the north and strengthen the soil with their roots, helping to prevent desertification.

At nearly 4,500km (2,800 miles) long, the belt should consist of roughly 100 billion trees by its scheduled completion date in 2050. But although 66 billion trees have already been planted, the project has faced – and continues to face – many challenges, including the loss of a billion poplar trees to disease in 2000, and continuing desertification caused by over-farming and poor use of land.

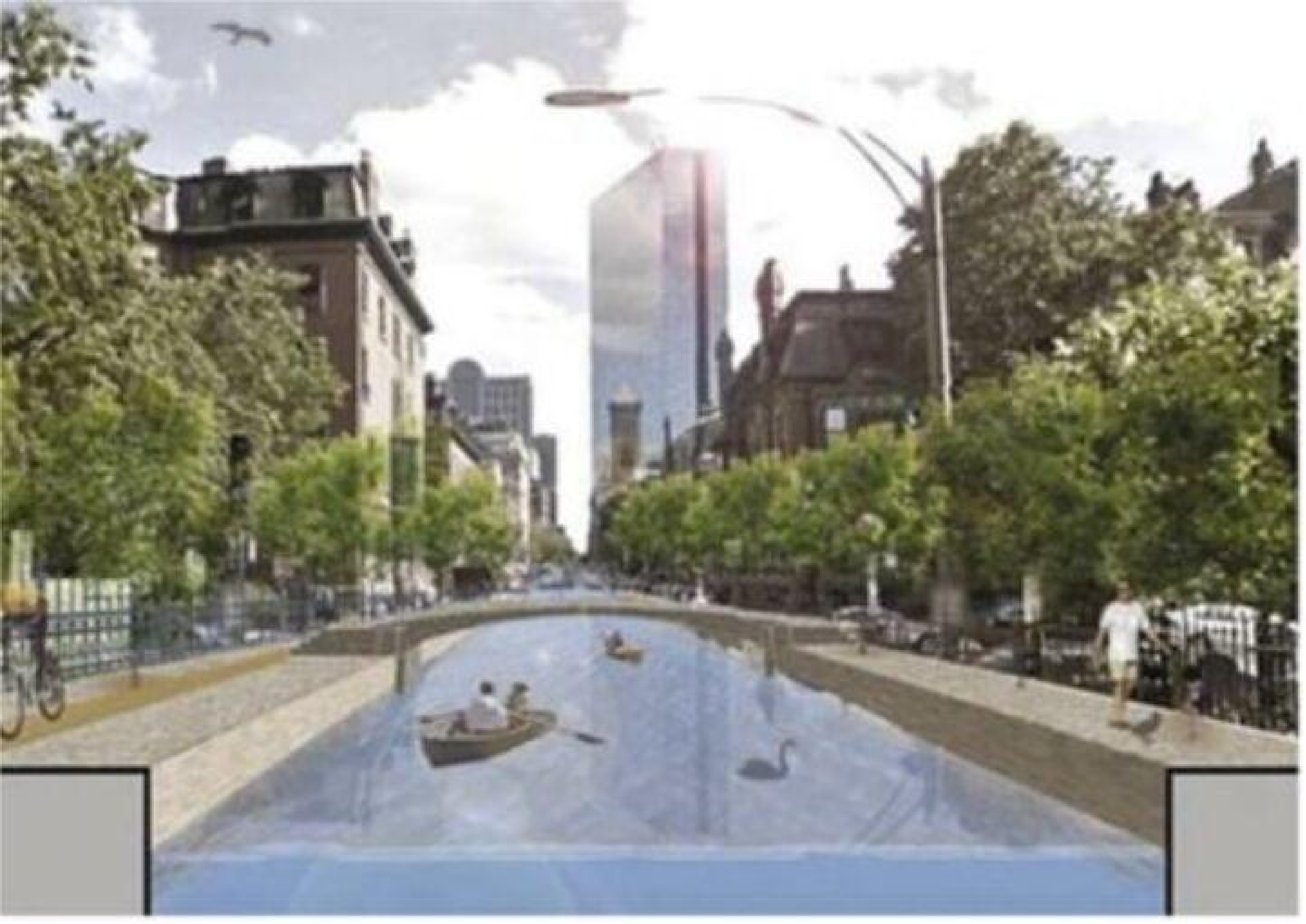


IMAGINE CHINA

8 WAYS TO BEAT THE FLOODS

Almost every year, some areas of the UK suffer severe flooding, a problem enhanced by climate change. But new ideas are on hand to help us stay dry

WORDS: **TOM HEAP**



1 REPLACE THE ROADS

Could Boston become the Venice of New England? Planners, scratching their heads in the face of increased local rainfall, rising sea levels and low-lying districts, suggested replacing the roads of Back Bay with canals. This would create a network of channels linking to new wetlands, enabling the management of water rather than its exclusion.

2 RELEASE THE DRONES

Early warning systems can mean the difference between life and death. But predicting the path and volume of water, especially flash floods, is very difficult. Even Saudi Arabia, which is an arid region, has seen 100 people killed by flash floods in the last five years. Scientists from Jeddah have been working on a drone system to give up to two hours notice before a flood hits.

3 BE WATER-RESISTANT

As many as five million homes are at risk of flooding in the UK. These houses won't be knocked down soon, so it makes sense to retro-fit the buildings rather than construct new ones. Houses can be fitted with flood-proof doors, ventilation bricks can be equipped with covers, and the the exterior given a water-resistant nano coating.

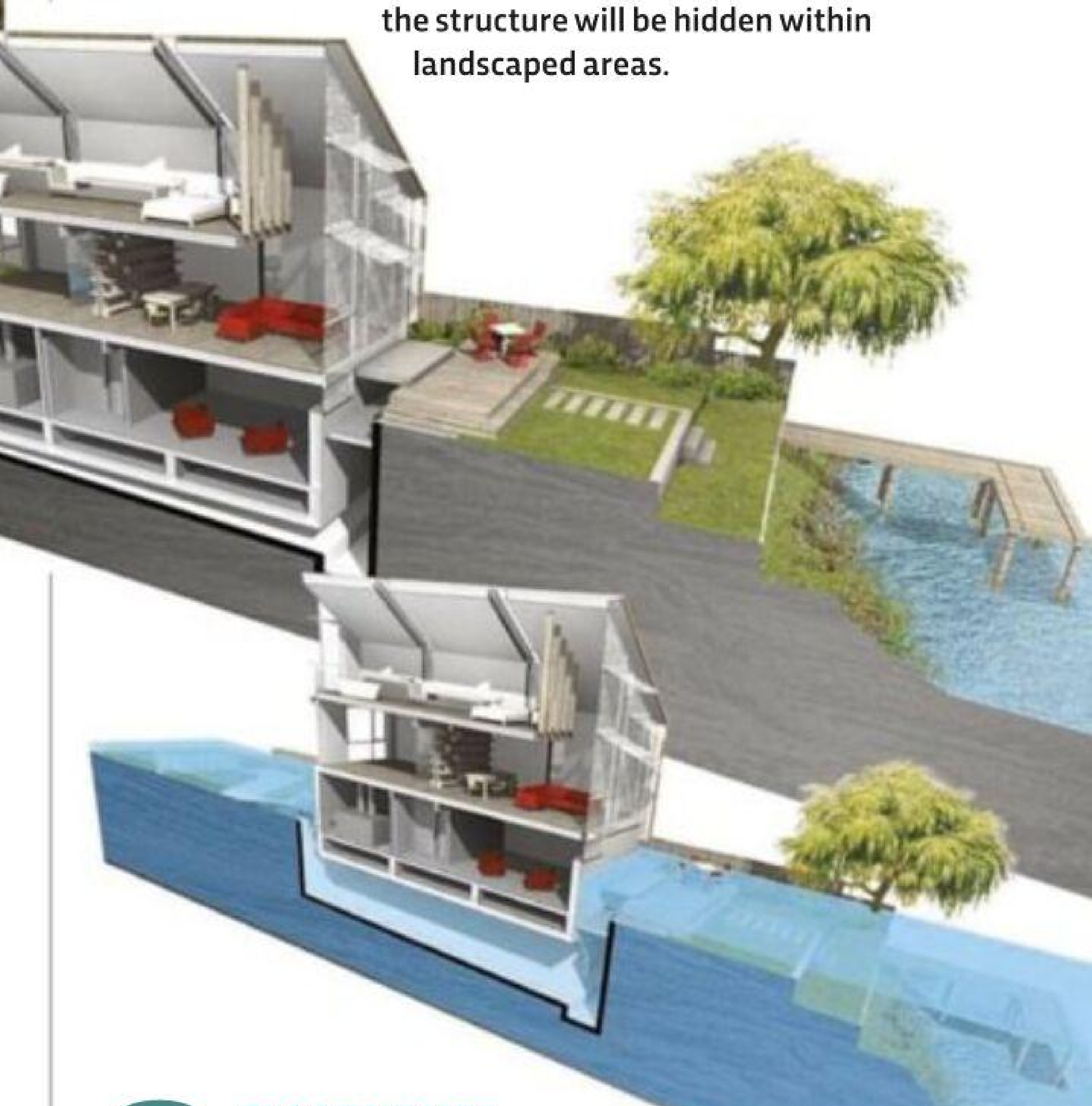
ENVIRONMENT AGENCY, BACA ARCHITECTS X2, GETTY X2, PRACTICALACTION.ORG, BIG U/REALBUILDBYDESIGN.ORG

4 TACTICAL RETREAT

Hard sea defences, such as concrete, are rather out of fashion. The ocean often batters them into submission after a few years, or they deflect the destructive energy elsewhere. In 2013, the Environment Agency built 7km of sea wall a long way inland, and the farmland between the barrier and the ocean became a salt marsh. This new wetland habitat is great for birds, but is also able to absorb the power of the sea and reduce the flood risk for hundreds of homes. It seems to work – locals stayed dry in the 2014 storms.

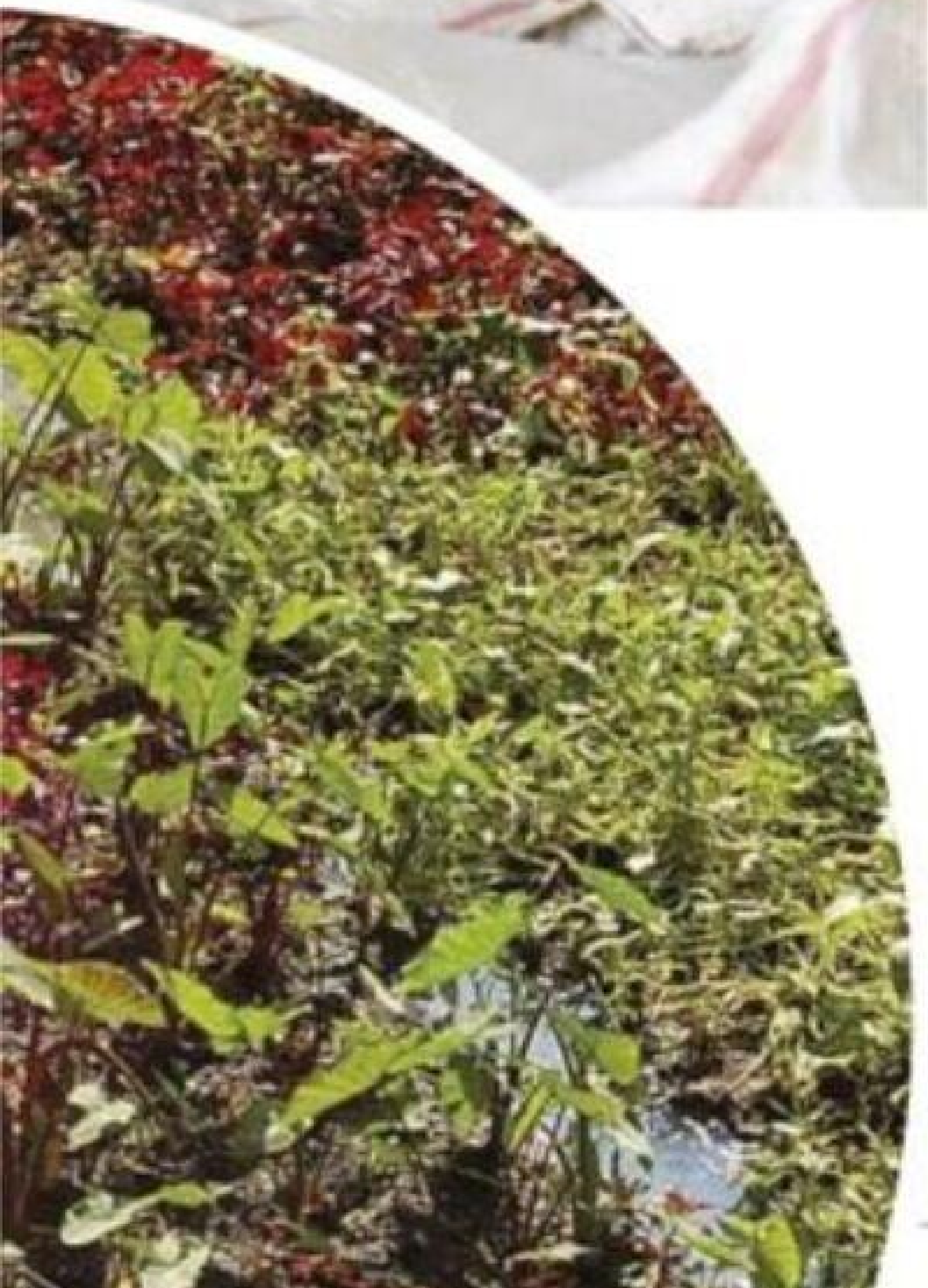
7 BUILD BIG WALLS

When towering skyscrapers are being lapped by rising oceans, there really is only one survival strategy: a sea wall. Hurricane Sandy struck New York in 2012, killing 53 people and causing almost $20bn (£13bn) of damage. To prevent destruction on this scale again, a wall is going up around the Big Apple. The 'Big U' is being masterminded by Danish and Dutch engineers, and will wrap around 16km of lower Manhattan's coast at a cost of $335m (£213m). To maintain the city's identity, the structure will be hidden within landscaped areas.



5 REMOVE THE RAIN

Jakarta floods regularly. In the last 20 years there have been four serious events – these have claimed hundreds of lives and cost millions of pounds in damage. The worst floods take place when high tide meets heavy rain, so the government's Weather Modification Technical Unit decided to make the rain fall elsewhere. They are using cloud seeding, which involves spraying particles into the clouds to encourage ice crystal formation and trigger rain. Planes have been scattering tonnes of salt above the ocean, therefore causing it to rain at sea rather than on land. While officials claim to have cut precipitation in Jakarta, many academics question this conclusion and want more proof. The authorities are undeterred and are requesting more aircraft for weather modification.



6 FARM ON THE WATER

To survive when the waters rise, we need food as well as shelter. In Bangladesh, where floods are a fact of life, floating gardens have been created. A raft of water hyacinth, which is a buoyant and persistent plant, is assembled and held together with bamboo. A layer of dung, soil and compost is applied, into which the crops are planted. Typically, one of these floating vegetable patches is about 1m x 8m, so it can be tended from a boat and towed to the marketplace. Bangladesh is also pioneering floating duck coops, allowing locals to sell eggs as well as veg.

8 FLOAT HOMES

There is a house in Marlow, Buckinghamshire that sits by the River Thames. From their lounge, the occupants will be able to watch the weather with serenity. The rains may pour and the river may rise... but so will their house. Most of the time, the structure rests on the riverbank, surrounded by garden like any other home. While it looks like a modern house from the outside, the cunning part lies beneath the main building. Waterproof concrete wraps around the basement level, and this sits in a reinforced yet porous hole in the ground. When the floods come, the whole house floats up, guided by four vertical posts. The dwelling can rise by a whopping 2.5 metres.

Tom Heap presents on *Panorama* and *BBC Countryfile.*

Cassandra Quave, Ph

THE NEW HERBALIST

Superbugs are becoming more resistant to ***antibiotics*** *by the day.* ***Cassandra Quave*** *is searching for a solution in forgotten herbal remedies*

Roaming around southern Italy, picking up interesting plants and chatting with the locals might sound like a holiday, but ethnobotanist Dr Cassandra Quave assures us it's not. "It's not a vacation," she says. "It's really hard work." It's also vital work – Quave and her team from Emory University in Atlanta, Georgia, are scouring the Mediterranean for medicines that could help tackle the mounting crisis of antibiotic resistance. In the US and Europe alone, 50,000 people die each year from infections caused by resistant bacteria they picked up during a hospital stay. Without new treatments, global deaths will soon soar into the millions. Quave believes that those treatments can be found in plants.

> "Over time and within these cultures, they've become attuned to these plant compounds and to the resolution of disease, and I think that's exciting"

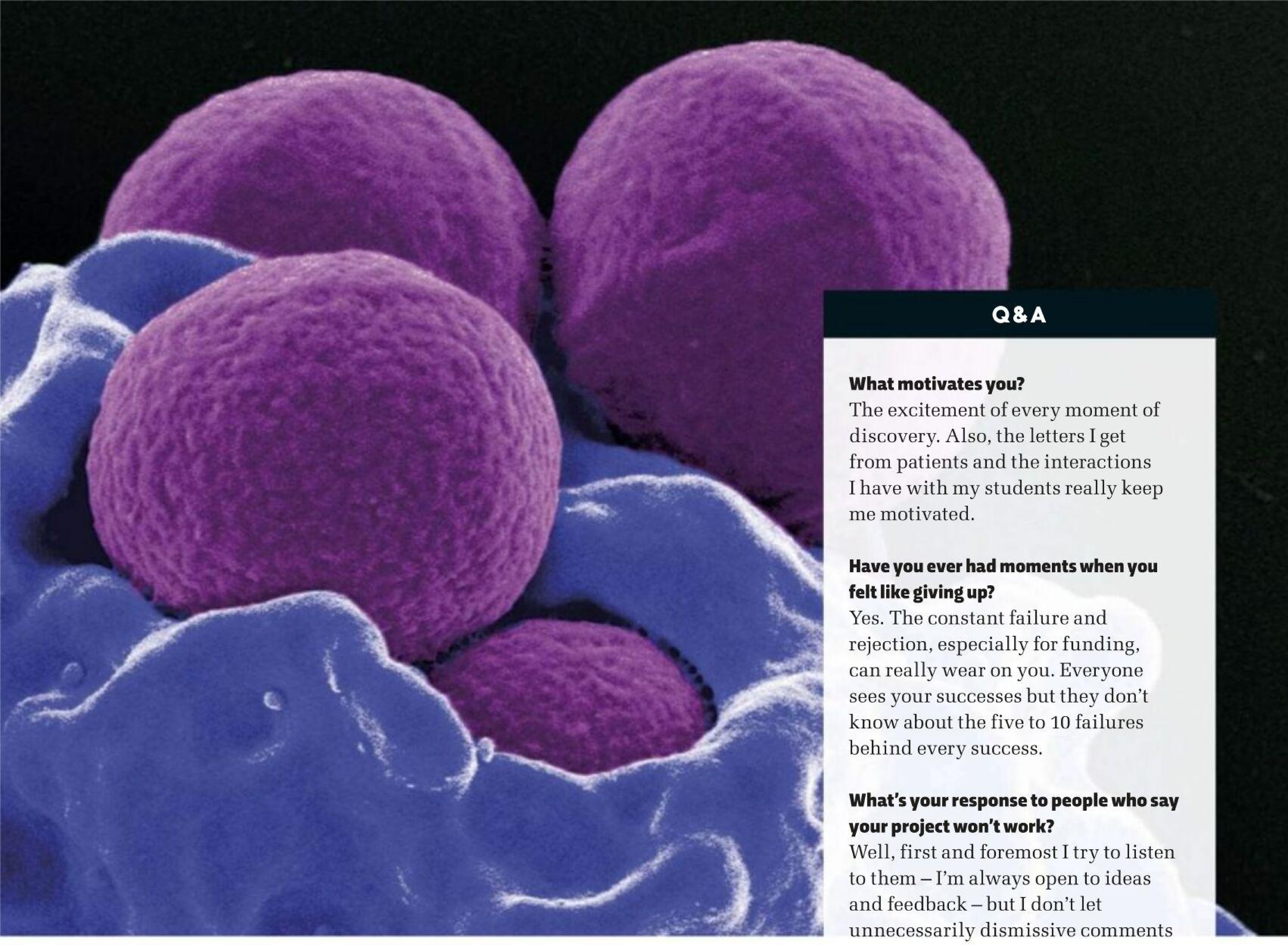
A self-described history of medicine geek, Quave talks to local people about plants that have been used, often for centuries, in their traditional medicines. She hopes to track down those with the greatest potential for fighting infection. She admits other researchers looking for new antibiotics are dismissive about her approach because they think plants have already been found lacking. "But no-one has looked at the scope of plants that we're looking at, and some of these are [already] being used in traditional medicines for fighting infection," says Quave. "Also, no-one has looked at the other potential ways that these might be acting beyond just killing bugs." What's curious about some of the plant extracts that Quave has tested is that they work in a different way to the antibiotics used in clinics today. As they stop short of killing their targets – working instead against microbial communication systems – the bugs shouldn't evolve resistance to these extracts, making them an exciting prospect for future antibiotics.

The approach could work against different species of bacteria, but top of Quave's hit list is methicillin-resistant *Staphylococcus aureus* (MRSA). Quave has something of a vendetta against the 'staph' bug: at the age of three, she was hospitalised for months with an MRSA infection after having part of her right leg amputated. Later, she got involved with science fair projects and became completely absorbed in the idea of bacterial resistance via news stories about *E. coli*-infested burgers. "I was an odd kid," she jokes. MRSA is notorious as the hospital 'superbug' that causes dangerous skin infections by using wounds, burns, drips and catheters to access deeper layers of the skin.

So has Quave found anything that could help? "In Italy, we asked people 'what plants do you put on the skin to treat infections and rashes... all of these kinds of things'," she says. "And sweet chestnut came up." The exact same plant that gives us roasted chestnuts at Christmas. In a recent paper, Quave's team showed that sweet chestnut leaf extract can block some of the toxic effects of MRSA and, in a mouse infected with the bug, decrease the area of skin affected, all without killing the bacteria.

Quave hopes to validate some age-old remedies. "This is giving cultural value to people who've been using these remedies for centuries. Perhaps a healer doesn't understand the intricacies of bacterial signalling, but over time and within these cultures, they've become attuned to these plant compounds and to the resolution of disease. I think that's exciting."

DAMON CASAREZ/REDUX PICTURES ILLUSTRATION: MARIO WAGNER



ABOVE: MRSA bacteria (the pink spheres) are resistant to many common antibiotics, making an infection hard to treat

LEFT: Extracts from sweet chestnut can block the effects of MRSA

Q&A

What motivates you?
The excitement of every moment of discovery. Also, the letters I get from patients and the interactions I have with my students really keep me motivated.

Have you ever had moments when you felt like giving up?
Yes. The constant failure and rejection, especially for funding, can really wear on you. Everyone sees your successes but they don't know about the five to 10 failures behind every success.

What's your response to people who say your project won't work?
Well, first and foremost I try to listen to them – I'm always open to ideas and feedback – but I don't let unnecessarily dismissive comments stop my work.

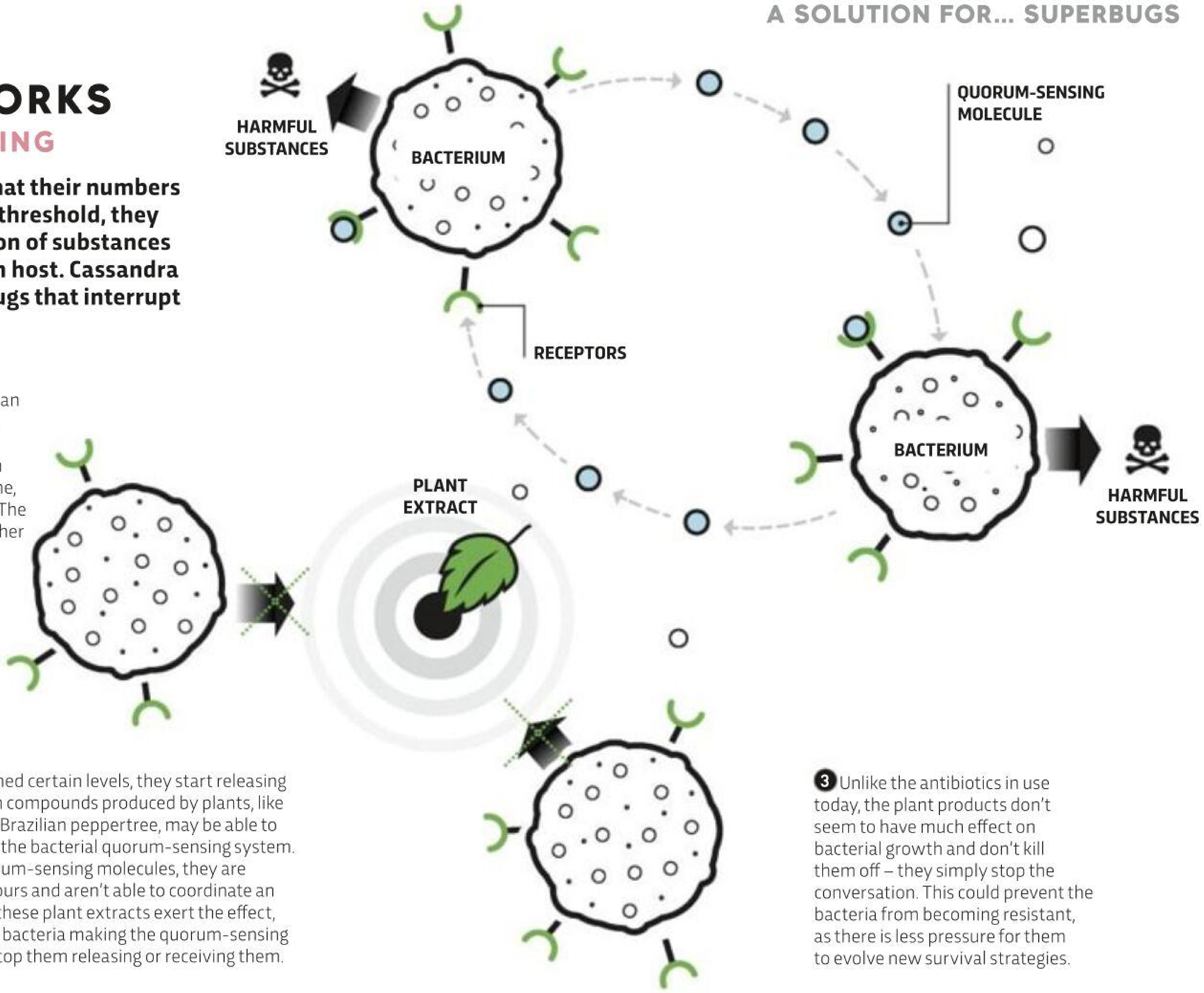
If you were able to rent out a billboard in Times Square, what would you write on it?
'Stop habitat destruction, and support preservation of biodiversity and cultural diversity.' That doesn't make a very sexy headline, but that would be my main message to the public.

What will your field of research look like in 2050?
I envision a new era of medicine in which we approach drug-resistant infections in a whole new way. Advances in our understanding of how synergistic therapies work will enable us to design better medicines that quickly reduce the severity of disease and achieve cures even for difficult-to-treat, antibiotic-resistant infections.

HOW IT WORKS

QUORUM SENSING

When bacteria sense that their numbers have reached a critical threshold, they switch on the production of substances that attack their human host. Cassandra Quave is looking for drugs that interrupt this process.



❶ Bacteria can't talk but they can use chemicals to communicate. Bacterial 'quorum-sensing' molecules attach to receptors in the bacterium's outer membrane, helping it sense its neighbours. The more bacteria there are, the higher the concentration of quorum-sensing molecules and the more of them each bacterium comes into contact with.

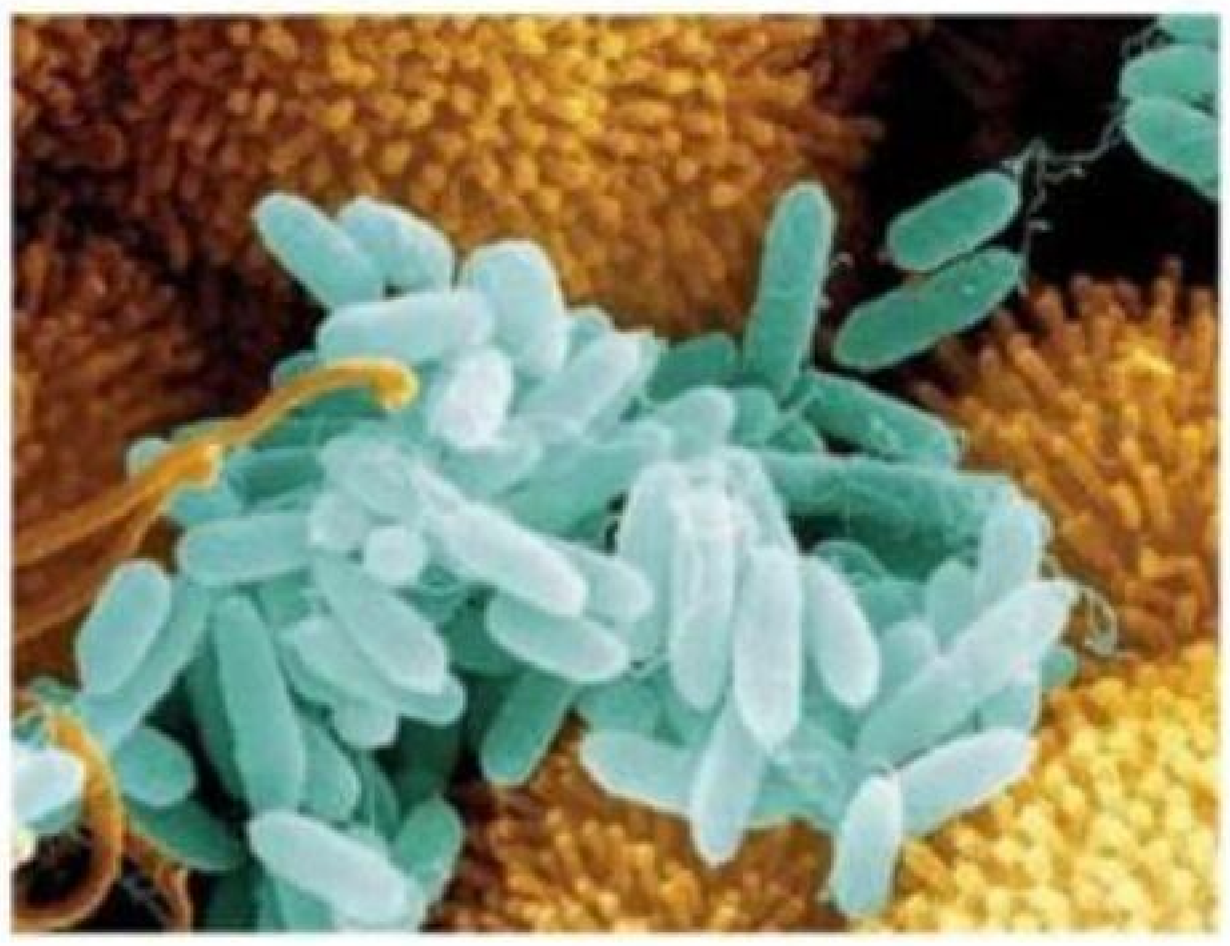
❷ Once the bacteria have reached certain levels, they start releasing harmful substances. But certain compounds produced by plants, like extracts of sweet chestnut and Brazilian peppertree, may be able to prevent this by interfering with the bacterial quorum-sensing system. If the bacteria don't detect quorum-sensing molecules, they are essentially deaf to their neighbours and aren't able to coordinate an attack. We're still not sure how these plant extracts exert the effect, however; they may prevent the bacteria making the quorum-sensing molecules in the first place, or stop them releasing or receiving them.

❸ Unlike the antibiotics in use today, the plant products don't seem to have much effect on bacterial growth and don't kill them off – they simply stop the conversation. This could prevent the bacteria from becoming resistant, as there is less pressure for them to evolve new survival strategies.

ALTERNATIVE MEDICINES

FUNGUS-FARMING ANTS

Leafcutter ants keep fungi gardens. They cut leaves to feed to the fungi, which feeds the ants' larvae. The fungi attracts lots of unwanted microbes, but the ants combat them with antimicrobials produced by Actinomycete bacteria that grow on their bodies – a potential source of new drugs being studied at the University of East Anglia. Most antibiotics used today come from the same group of bacteria.



CATFISH MUCUS

The striped dwarf catfish, found in Asian estuaries, secretes an antibiotic-filled mucus from its skin. Many fish produce mucus that's rich in antimicrobials, because it helps protect them from disease. However, Indian researchers found that slime from the catfish was particularly potent against bugs that infect humans, including *Pseudomonas aeruginosa*, which causes pneumonia.

THE ENDS OF THE EARTH

Scientists from the University of Illinois at Chicago are searching in places that until recently remained unexplored for antibiotics. They plunge test tubes into Iceland's hot springs and the muck at the bottom of freshwater lakes to look for bacteria that produce novel compounds. They've already found bacteria in Lake Michigan that produce antibiotics capable of killing the tuberculosis bug.

GETTY X3, SCIENCE PHOTO LIBRARY, JARROD J SCOTT, ALAMY ILLUSTRATION: ACUTE GRAPHICS

PROBLEM 2

ENVIRONMENTAL DAMAGE

Earth's crust is covered by land, sea and air, and thanks to the centuries we've spent living on, working in and travelling through them, all three are now in bad shape. The manner in which we've exploited the planet's terrain, oceans and atmosphere has led us to a point where much of those environments are useless for farming, unsuitable for building on and devoid of all but the most extreme forms of life. What can we do to remedy that?

SOLUTIONS FOR

THE PLASTIC PROBLEM – HOW TO SOLVE THE PLASTIC PROBLEM P44
OUR ENERGY NEEDS – POWER TOOLS TO SAVE THE PLANET P53
GLOBAL WARMING – 5 MEGA IDEAS TO FIX THE CLIMATE P58
CLIMATE CHANGE – THE CLOUD CHASER P68
AIR POLLUTION – A BREATH OF FRESH AIR P72
LANDSCAPE DESTRUCTION – THE UNSUNG ECO-HEROES P78

GETTY

GETTY

HOW TO SOLVE THE PLASTIC PROBLEM

By 2050 there could be more plastic in the sea than fish. But some genius inventions could help clean up the oceans

WORDS: **JOSH GABBATISS**

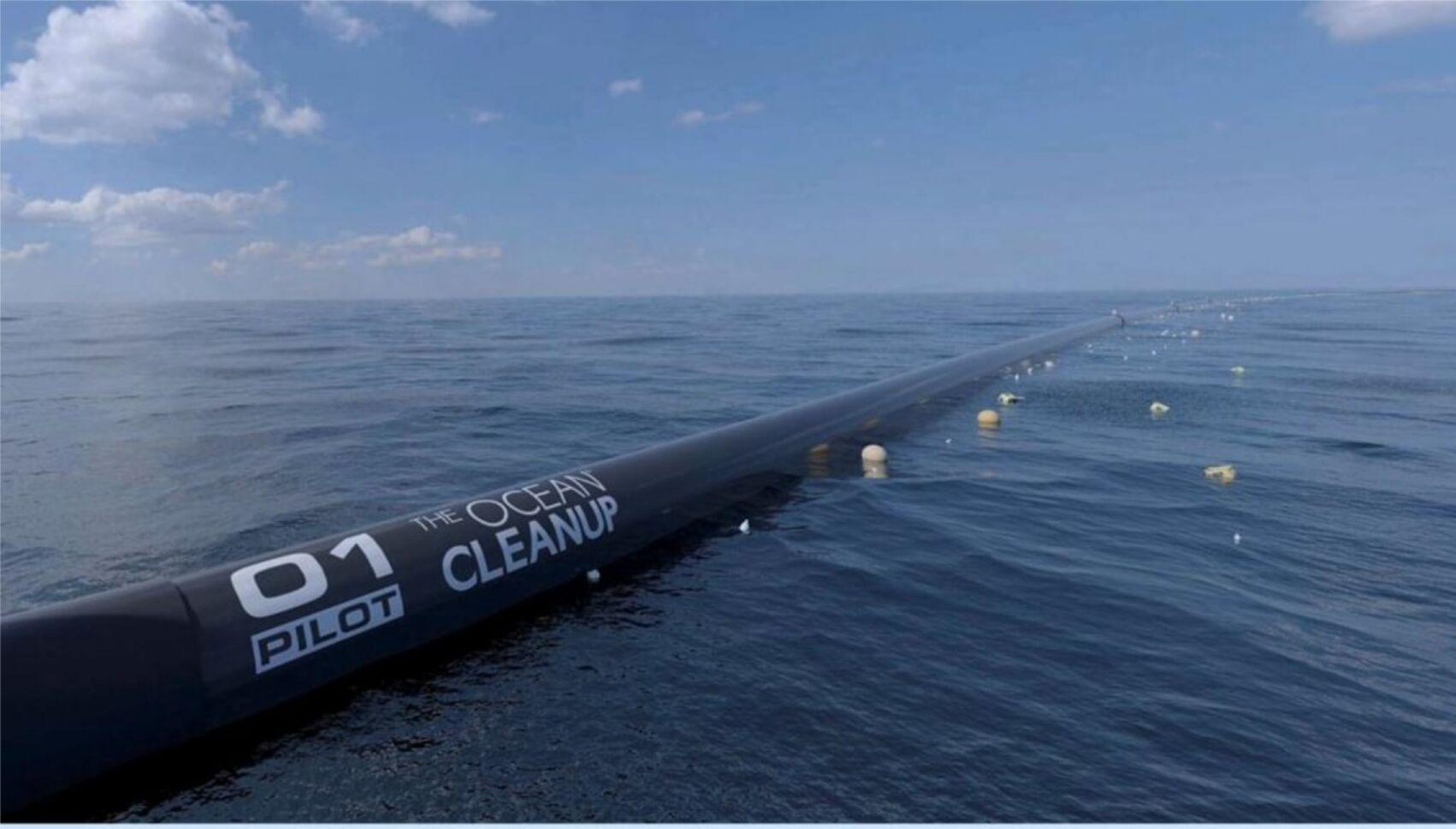
There are over five trillion pieces of plastic in the world's oceans. The floating island of rubbish that's supposedly found at the centre of the Pacific Ocean, dubbed the 'Great Pacific Garbage Patch', has captured the public's imagination, but even this doesn't do justice to the problem. In reality, if you stood on a boat at that site you would see no enormous plastic island, but rather endless tiny fragments floating on the surface of the ocean. According to one estimate, this plastic soup covers an area twice the size of the continental United States.

As plastic moves through our seas it breaks down into smaller pieces – the kind of pieces that can easily be swallowed by marine life. And the problems continue deeper down. Scientists are increasingly finding deposits of plastic at the bottom of the oceans, even as far down as the 10km-deep Mariana Trench.

The facts are horrifying, but many of the impacts that plastic will have on ocean ecosystems, marine creatures and, by association, us, remain to be seen. Scientists and entrepreneurs are currently working on ways to halt the flow of plastic into our oceans, and get rid of the stuff that's already there, before the problem gets even worse.

CAPTURE IT

Perhaps the most natural response to the plastic problem is to try to clean up what's already there. "Of course, clean-up is really important," says Prof Richard Thompson, head of the International Marine Litter Research



The barriers that The Ocean Cleanup will deploy measure 1-2km in length and aim to capture larger plastics before they degrade

Unit at Plymouth University, "and it's our first reaction as humans when we've made a mess." Such reactions vary wildly in scale, from local 'beach cleans' to large-scale, high-tech projects launched by the likes of The Ocean Cleanup.

The Ocean Cleanup was initially conceived by the then 18-year-old Dutch entrepreneur Boyan Slat. His highly ambitious project aims to use huge barriers to passively trap plastic as it moves around ocean gyres – the large circulating currents that keep the floating plastic in place. By anchoring the barriers in deep, slow-moving water, the idea is that the system will move slower than the plastic surrounding it, allowing the debris to accumulate against the barrier. The team behind the project estimates that deployment of their systems could clean up approximately 50 per cent of the Great Pacific Garbage Patch within five years. It's an exciting proposal, and one that has captured people's imaginations, most notably venture capitalists like Peter Thiel who have followed through on this enthusiasm with sizeable cash injections. In total, The Ocean Cleanup has received $31.5m in donations since its inception back in 2013. The team is aiming to roll out a pilot study in the North Pacific sometime this spring, and their first fully operational system will be launched later in the year.

While it may be appealing to the great and the good of Silicon Valley, The Ocean Cleanup has attracted its fair share of criticism from the scientific community. Concerns have been raised over everything from the viability of the proposed barriers to their effects on local ecosystems. Perhaps the biggest issue raised, however, is that glamorous initiatives like Slat's draw attention away from the key problem, which is the sheer quantity of litter entering the seas. "It's a little bit like you're filling the bath, you leave the taps on and go downstairs to make a cup of tea," says Thompson. "Then you come back upstairs to find the bath is overflowing – do you start by mopping up the floor, or do you start by turning off the tap?"

What worries Thompson and others is that projects like The Ocean Cleanup ➜

His ambitious project aims to use huge barriers to passively trap plastic as it moves around circulating ocean currents

WHAT'S THE ALTERNATIVE?

Can we reduce our reliance on plastic? Here are five innovative materials that are in development

1

CARBON DIOXIDE AND SUGAR

As plastics tend to be made using fossil fuels, the search for alternatives is part of the journey towards a more sustainable future. Currently, 4 per cent of global oil production goes into plastic, but scientists are exploring ways to bring this down to zero. A sugar- and carbon dioxide-based substitute for the plastic polycarbonate (used for glasses lenses, DVDs and greenhouses) has been developed by a team at the University of Bath. Not only does their method bypass fossil fuels, but the resulting material is transparent, strong and biodegradable.

2

AGAR

Easily extracted by boiling red algae, agar is used to make confectionery in Japan. In a project called Agar Plasticity, the Tokyo-based design collective AMAM suggested that this gelatinous substance could be a viable plastic alternative. By heating agar, pouring it into moulds and then freezing it, the team was able to make a selection of plastic-like products and packaging (the bottle pictured has been wrapped with the agar 'plastic'). The designers are now looking to partner with industry so that they can access the scientific and technical know-how to take their idea to the next level.

3

FUNGI

The bulk of a mushroom's body consists of a mass of underground filaments called the mycelium. By employing mycelia grown on agricultural waste, New York company Ecovative Design is creating a new plastic alternative. A mixture of fungi and their food source can be placed into a mould, such as food packaging or a piece of furniture. Then, once the mould has become filled with a dense mass of mycelia filaments, it is heat-treated to kill off the fungi, which results in a product that is durable but also totally biodegradable.

4

EDIBLE PACKAGING

Food and drink packaging is going to require a huge overhaul if we are to solve the plastic problem. One viable option could be packaging replacements that are just as edible as the products they contain. An example is Skipping Rocks Lab's 'Ooho!', an edible sphere of water made from seaweed extract that you can pop into your mouth (pictured). The US Department of Agriculture has developed a replacement for the thin plastic films used in food packaging, made from the milk protein casein. These films are biodegradable, sustainable and edible, and far better at preventing food spoilage.

5

CHICKEN FEATHERS

Enormous quantities of feathers are produced as a by-product of the poultry industry, and they are generally treated as waste. However feathers are composed almost entirely of keratin, a tough protein also found in animal hooves and horns. This means that in theory they could be used as strong, structurally sound, natural replacements for regular plastics. Researchers at the University of Nebraska-Lincoln have attempted to harness this potential, by pounding feathers into a fine powder, then mixing with chemicals to make the keratin molecules bind together.

ERWIN ZWART/THE OCEAN CLEANUP, KOSUKE ARAKI, ALAMY

WHERE OUR PLASTICS GO

Around 300 million tonnes of plastics are produced annually.

As of 2015, 8.3 billion tonnes of plastics have been produced by humans since the early 1950s.

Of the 8.3 billion tonnes, 6.3 billion tonnes has become waste.

By 2050, the total amount of plastic produced by humankind is projected to have risen to 34 billion tonnes.

Over 480 billion plastic bottles were sold in 2016 – that's more than 60 bottles for each person on the planet.

New bottles are made from only 6.6 per cent recycled plastic.

Up to one trillion plastic bags are discarded every year too.

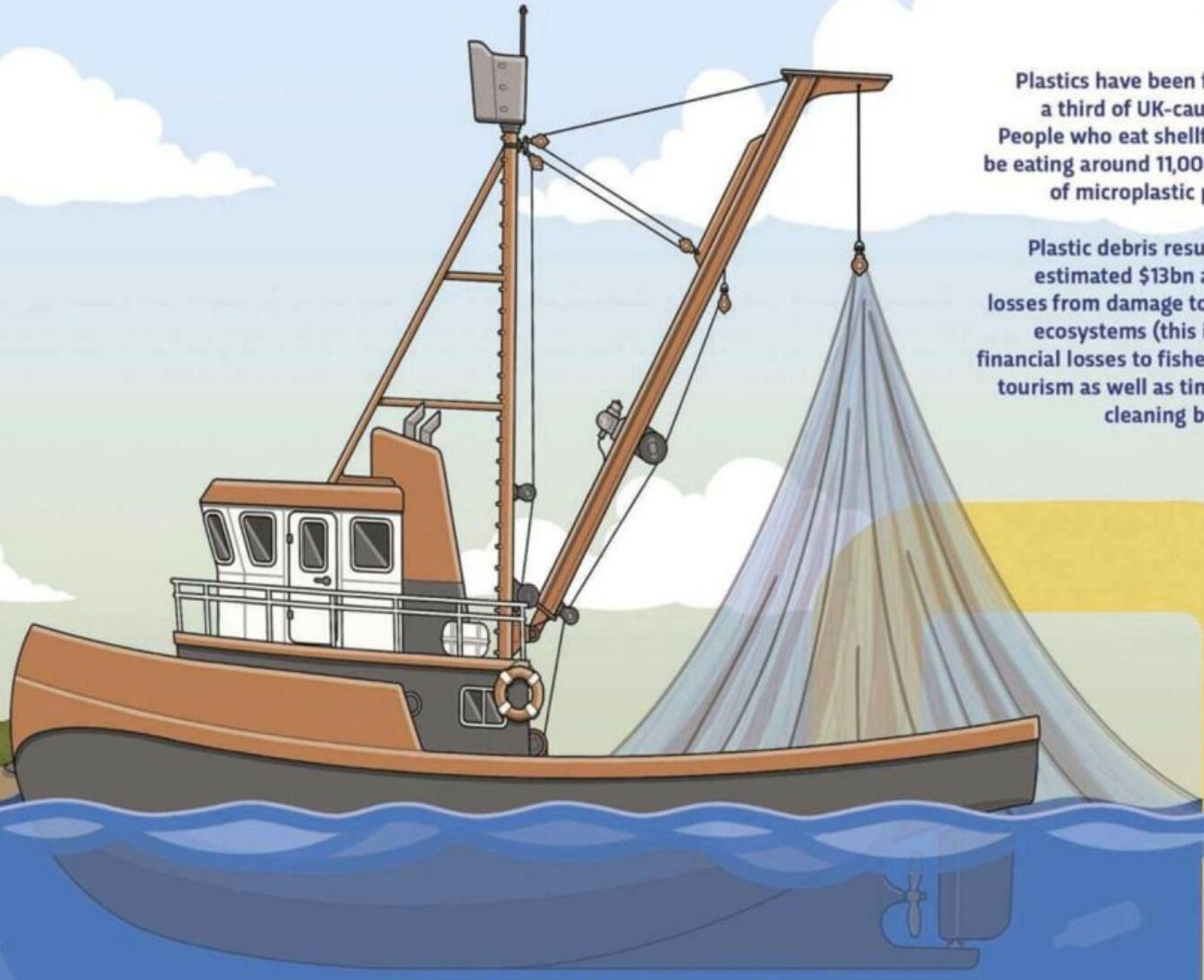
Only around 9 per cent of plastic gets recycled.

12 per cent gets incinerated.

The rest accumulates in landfills or the natural environment.

As much as 13 million tonnes of plastic enters the ocean globally each year – equivalent to the mass of around 85,000 blue whales.

The amount of plastic entering the oceans is expected to more than double within 10 years.



Plastics have been found in a third of UK-caught fish. People who eat shellfish may be eating around 11,000 pieces of microplastic per year.

Plastic debris results in an estimated $13bn a year in losses from damage to marine ecosystems (this includes financial losses to fisheries and tourism as well as time spent cleaning beaches).

On land, plastic bottles will take 450 years to decompose. At sea, they'll never truly disappear.

The bottles break down into microplastics, less than 5mm long.

180 species of marine animals have been documented feeding on plastic.

There are 51 trillion microplastic particles in the oceans – 500 times more than stars in the Milky Way.

70 per cent of ocean waste sinks to the floor, meaning floating debris is just scratching the surface.

ILLUSTRATION: RAJA LOCKEY

overcomplicate an issue that requires basic work to be done first. “If I were a rich philanthropist, I would be putting 99 per cent of my money into stopping the flow, and 1 per cent into clean-up,” he says.

Dr Matthew Savoca, who studies the effects of plastic pollution on marine life at the NOAA Southwest Fisheries Science Center, has a more positive take. “Assuming it doesn’t scoop up more ocean life than plastic, why not give it a shot?” he says. “However, I think [The Ocean Cleanup] would be most effective at or near the mouths of large commercial harbours and at the mouths of rivers, since we know that’s how most plastic gets out to sea in the first place.” While this is not the stated aim of that project, a far smaller device – the Seabin – has been designed by two Australians to clean up rubbish in just such areas. Using solar-powered pumps, Seabins sit at the surface of the water and suck in the debris that accumulates around harbours and other seaside structures.

Another suggestion for plastic collection involves underwater drones. These autonomous vehicles could whizz around plastic-saturated areas of the ocean, swallowing rubbish with their circular ‘jaws’ while keeping fish away using a sonic transmitter.

These are ingenious solutions, and maybe a *bona fide* success story will help to ease the tension between those developing the projects, and the people who want to prevent the plastic getting there in the first place. After all, as Savoca points out: why not do both?

GOBBLE IT UP WITH MICROBES

Bacteria are potentially the most versatile creatures in existence, capable of making a home in pretty much any environment on Earth. It is perhaps unsurprising, then, that in recent years scientists have found evidence that some have evolved the capacity to break down plastics. In 2016, for example, a Japanese team identified a bacterium capable of biodegrading PET – a plastic found in everything from polyester clothing to water bottles – prompting speculation that bacteria could be employed to stem the tide of plastic pollution.

SEABIN PROJECT

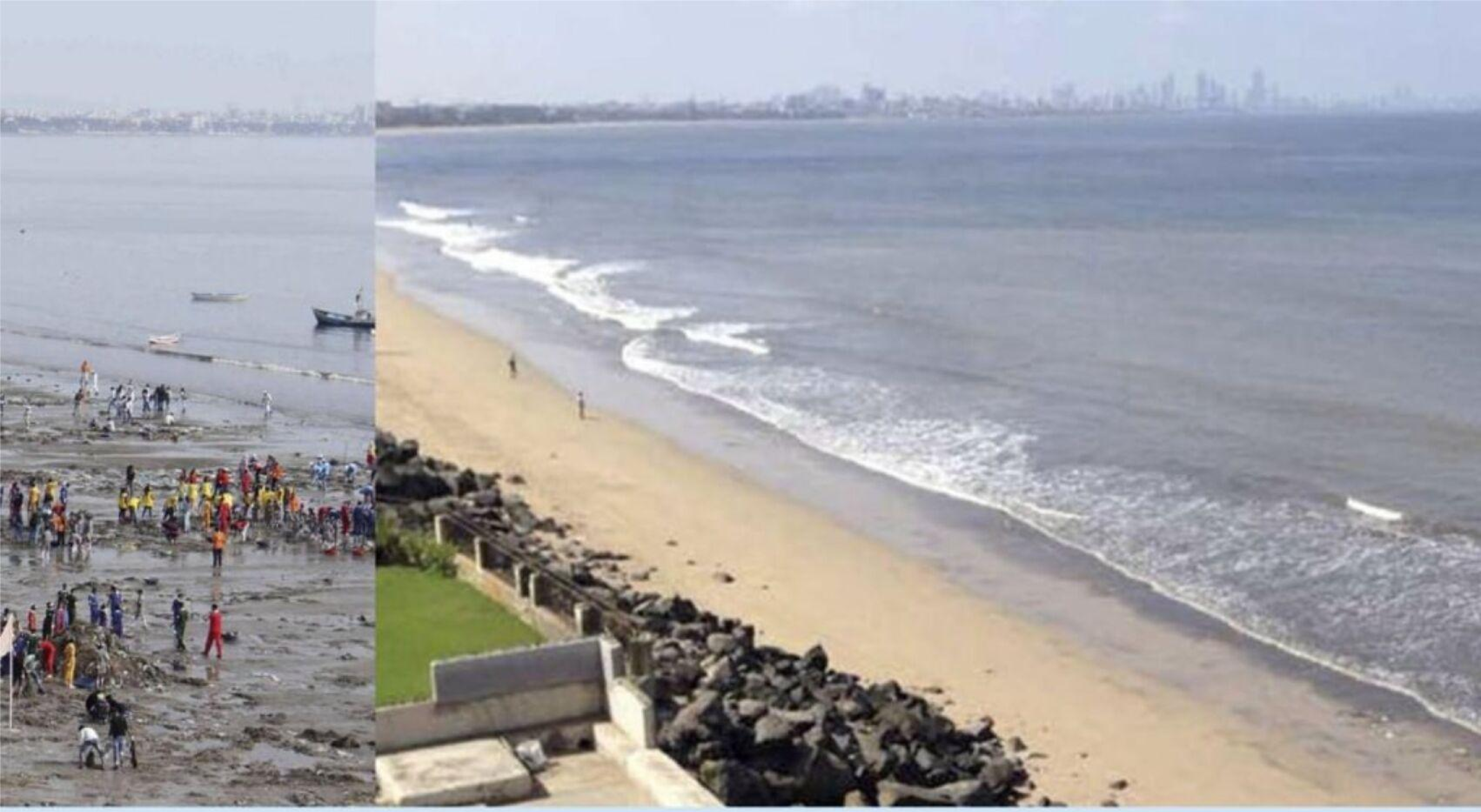
Seabins are designed to collect rubbish from harbours and ports, and can suck in 1.5kg of floating waste per day

Dr Linda Amaral-Zettler, a microbial ecologist working on the ‘plastisphere’ – the community of creatures living on ocean plastics – says it’s wrong to think of plastic as a sterile environment. “When you do the experiments, you find there are some microbes that are incredibly well suited to colonising plastics,” she explains. Her work has shown distinct genetic differences between bacteria inhabiting plastic and those in the surrounding water, so the concept of bacteria adapting to life in the Plastic Age is not that far-fetched. “But it’s one thing to colonise, it’s another to actually break down and digest plastic,” she adds.

While plastics do degrade naturally through UV radiation and physical processes, and bacteria may be playing some role in this, it doesn’t mean all the plastic is simply vanishing into their tiny bodies, never to be seen again. In fact, some microbes might even be breaking down the plastic into ever smaller particles, which are not only harder to detect and clean up, but could be damaging marine ecosystems. Plastic-munching microbes are an intriguing area of research, and certainly worth exploring further. But with the plastic piling up fast, we might not be able to rely on bacteria to do our dirty work for us.

Ultimately, plastics are not our enemy. They are durable, lightweight, inexpensive and

ALAMY, AFROZ SHAH



ABOVE LEFT AND RIGHT: A total of 5,000 tonnes of litter was cleared from a 2.5km-long stretch of Mumbai's Versova beach over the course of 85 weeks. Before the volunteers set to work, waste was piled over 1.5m high

incredibly useful. The major issue is that around 40 per cent of the plastic we produce is going into single-use items, such as cotton buds, drinking straws, carrier bags and plastic forks, which have a long life following disposal.

Fortunately, we're beginning to see more projects that repurpose discarded plastics. Not only can plastics be recycled to make the usual suspects, such as packaging, but they can be transformed into more specialist products such as clothes. Some companies, for example, melt down plastic bottles and turn them into fibres that can be woven into fabrics, a process that uses 50 per cent less energy than producing polyester, the plastic most widely used in clothing, from scratch.

Plastics can also be used as fuel, with new technologies allowing us to efficiently convert them into diesel and gasoline. By heating plastic in a controlled way, coupled with a catalyst, it is possible to produce fuel that doesn't even need refining and is ready to use. All of this means less plastic leaking out of the system and ending up in the oceans. Eventually, we could see a fully circular 'plastic economy', though this would require major changes at an industry level in order to make plastic easier to recycle and reuse.

Watch a video that went viral of a diver swimming through a cloud of plastic **bbc.in/2kNkIHu**

Josh Gabbatiss is a science writer based in London. He tweets from @Josh_Gabbatiss.

HOW YOU CAN HELP

1 AVOID SINGLE-USE PLASTICS

The culprits here should be familiar to everyone: carrier bags, bottles and drinking straws. Purchase a 'bag for life', carry a reusable bottle, and sip drinks straight from the glass.

2 GIVE UP CHEWING GUM

Chewing gum is made from synthetic rubber – which is a plastic – and shockingly around 100,000 tonnes of the stuff is discarded every year. Is minty-fresh breath really worth that?

3 GO ON A BEACH CLEAN

Organisations like the Marine Conservation Society conduct cleans up and down the country, removing rubbish from the beaches and raising awareness of the ocean environment.

4 RECYCLE!

We've all heard this one by now, but currently only a third of recyclable plastic used by UK consumers is recycled. So swot up on your local rules and get into the recycling habit!

5 GO MICROBEAD-FREE

A UK ban is coming into force this year for many products containing microbeads. Be wary: it won't cover 'leave-on' products such as sunscreen and make-up, so read ingredients lists.

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POWER TOOLS
TO SAVE THE PLANET

After almost two centuries of us relying on fossil fuels, we're now seeing the damage it's causing to Earth. Here are some of the most promising eco-technologies to wean us off coal, oil and natural gas…

WORDS: **DUNCAN GEERE**

ISTOCKPHOTO, ALAMY X2, GETTY, GOTEBORG ENERGI

TRANSPORT

The most promising green technologies that might let us stay on the roads after we're forced to ditch the diesel

Inside the fuel cell, hydrogen splits into ions and electrons, the latter of which generate electricity, powering the motor

POTENTIAL CO_2 REDUCTION BY 2050

ELECTRIC CARS	**4 gigatons**
ELECTRIC BIKES	**0.96 gigatons**
ELECTRIC TRAINS	**0.5 gigatons**

SOURCE: Drawdown (Paul Hawken, Penguin, 2017)

Fuel cell cars

The fuel that powers the Sun – hydrogen – could be a viable alternative to petrol

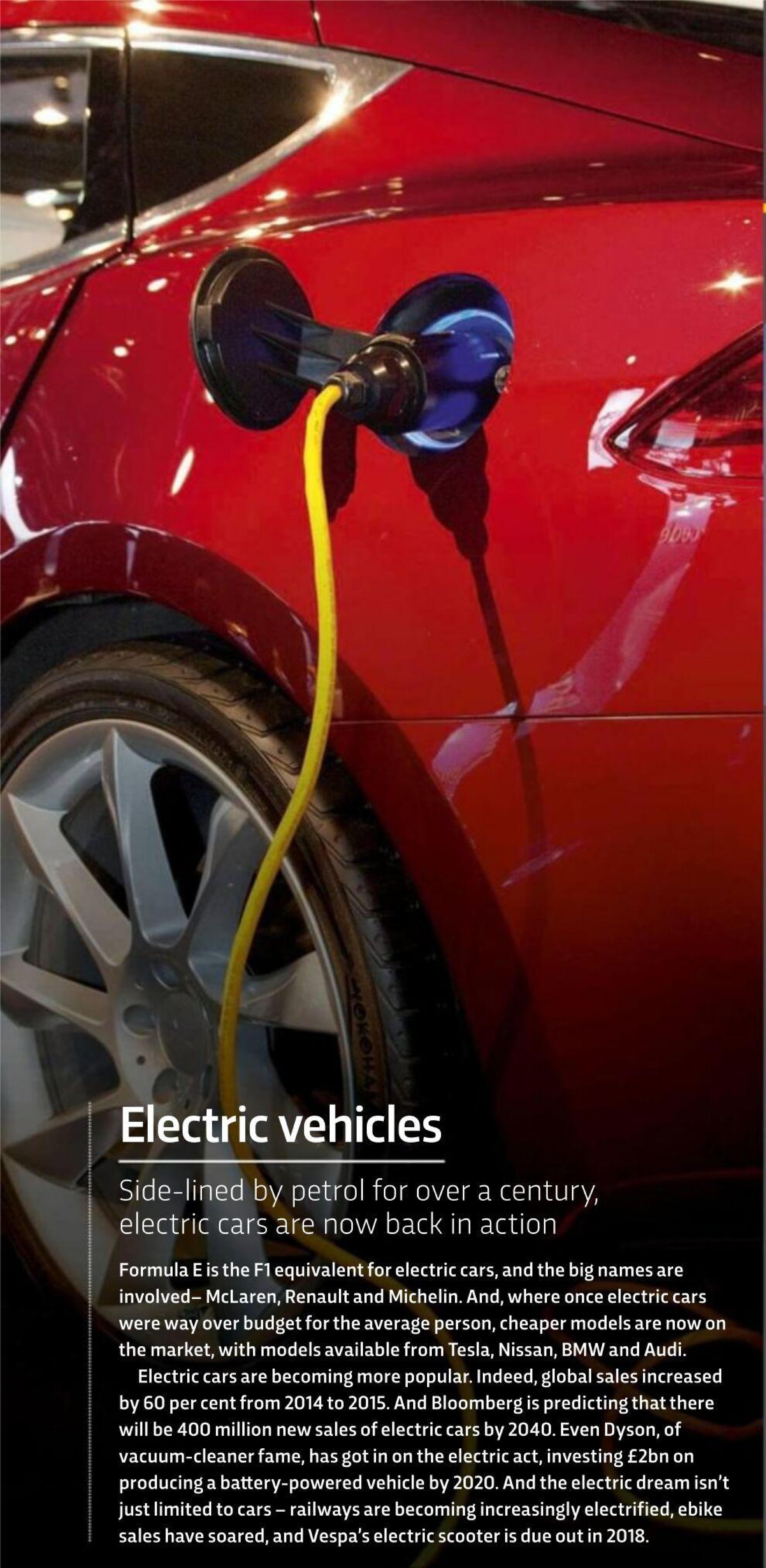
Cars equipped with a fuel cell are electric, but have no battery. Instead, they fill up with hydrogen at a pump, which is then mixed with oxygen in the air to produce electricity that powers the motor. The benefit of hydrogen cars is that the only thing that comes out of the tailpipe is water vapour.

But there are downsides. About 95 per cent of US hydrogen is produced from natural gas – a fossil fuel. Cleaner methods don't get anywhere near the same level of efficiency. Hydrogen is also a fairly dangerous substance – as seen in the Hindenburg disaster, where the airship went up in flames. Keeping hydrogen safe in a metal can hurtling down the road at 80mph is a tricky task.

Every technology has its limitations, yet the potential of fuel cell cars is huge. A 'corridor' of hydrogen fuelling stations is currently being built across Europe, paving the way for a fuel cell future.

Recharging rather than refuelling – a trip to the pumps is likely to involve filling your car's battery instead of its fuel tank in the years to come

ISTOCKPHOTO, ALAMY X2



POWER

We need more homes but we really need ways to power them cleanly

The emissions from Reykjanes Power Station in Iceland may look like nasty pollutants, but are in fact only steam

Electric vehicles

Side-lined by petrol for over a century, electric cars are now back in action

Formula E is the F1 equivalent for electric cars, and the big names are involved– McLaren, Renault and Michelin. And, where once electric cars were way over budget for the average person, cheaper models are now on the market, with models available from Tesla, Nissan, BMW and Audi.

Electric cars are becoming more popular. Indeed, global sales increased by 60 per cent from 2014 to 2015. And Bloomberg is predicting that there will be 400 million new sales of electric cars by 2040. Even Dyson, of vacuum-cleaner fame, has got in on the electric act, investing £2bn on producing a battery-powered vehicle by 2020. And the electric dream isn't just limited to cars – railways are becoming increasingly electrified, ebike sales have soared, and Vespa's electric scooter is due out in 2018.

Renewables

Earth's potential energy is immense. Harnessing as much as possible could be the solution

WIND ENERGY

Wind farms now account for 3.7 per cent of global electricity usage. There's growing investment in offshore windfarms – £21.5bn was invested in 2016, 40 per cent up from the previous year.

TIDAL POWER

The tides are even more predictable than the winds. Historically, very few sites were suitable for tidal power, but improvements in turbine technology have made more places viable. According to a 2001 World Energy Council survey, the energy potential of coastal tides is over 450 gigawatts and could provide up to 25 per cent of US electricity needs.

GEOTHERMAL

Sitting atop a planetary 'hot spot' can have its downsides – such as when a volcano erupts. But, countries like Iceland and Japan, have tapped into these heat sources to generate power. Cheap, reliable and eco-friendly, geothermal energy works by pumping water below the surface, where scorching temperatures turn it into steam.

When light shines on a solar cell, it creates an electric field across layers of semi-conducting material, usually made from silicon

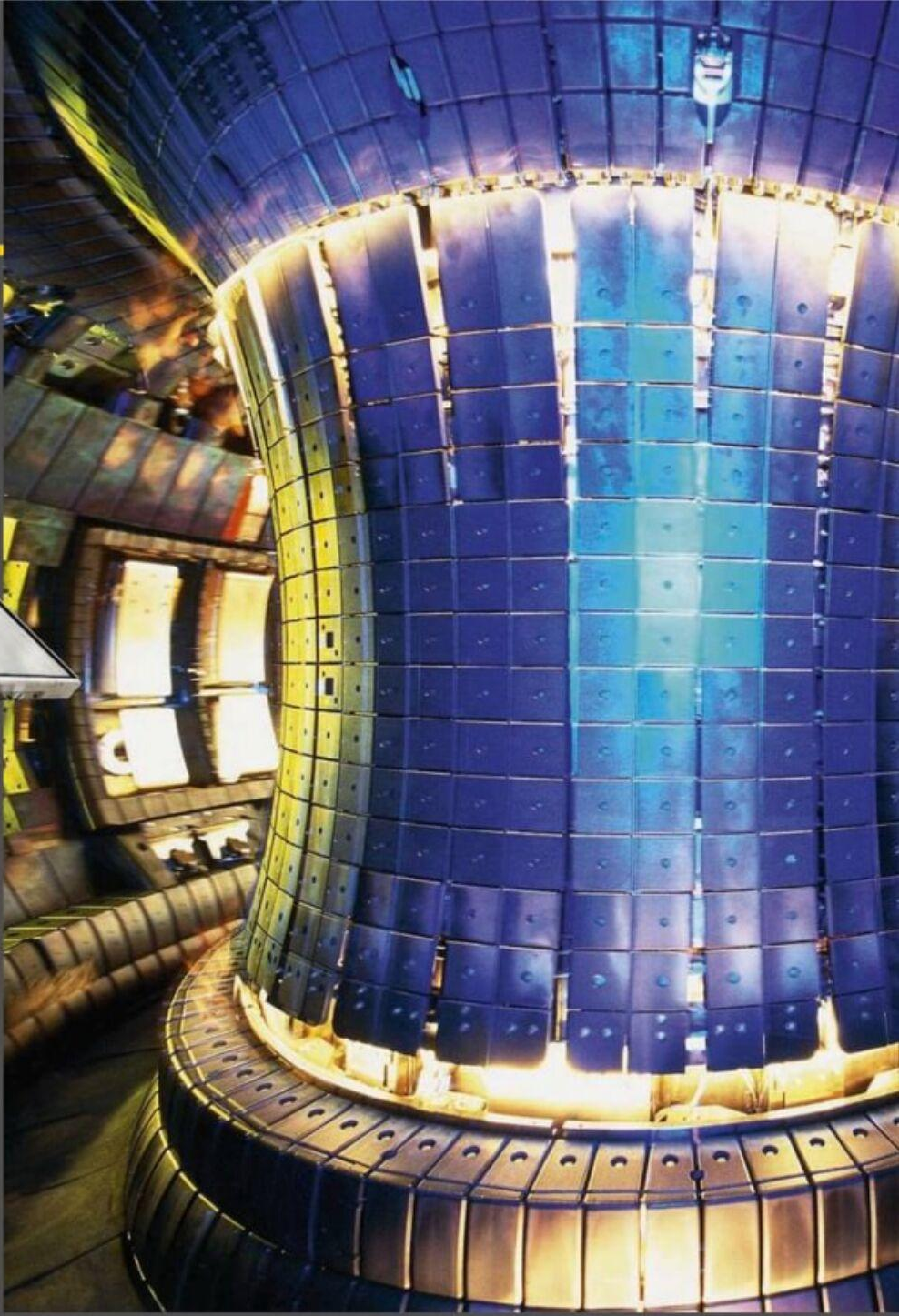
Home solutions

Generating energy in your own home not only boosts efficiency, it could also save you money

MICROGENERATION
The current system of national grids and huge centralised power plants is less efficient than a 'microgeneration' system, where we all generate some of our own power, and pay for the difference between what we create and what we use.

SOLAR POWER
In California, Spain and Japan, solar energy is already cheaper than grid power for much of the year, while Europe and China offer financial incentives too. Some companies have developed photovoltaic glass that can be used as windows and skylights – or even on pavements. Solar is also great for heating and cooling your home. The Sun's energy can be used to warm a tank of water, while solar-driven heat pumps can provide cooling solutions.

GROUND SOURCE HEAT PUMP
Similar technology can be used to exchange heat with the ground. As the temperature below the surface stays between 7°C and 24°C year-round, in the winter, heat can be drawn up, and in the summer it can be sent down. Systems aren't cheap to install, but you'll save thousands from your energy bills in the long term.



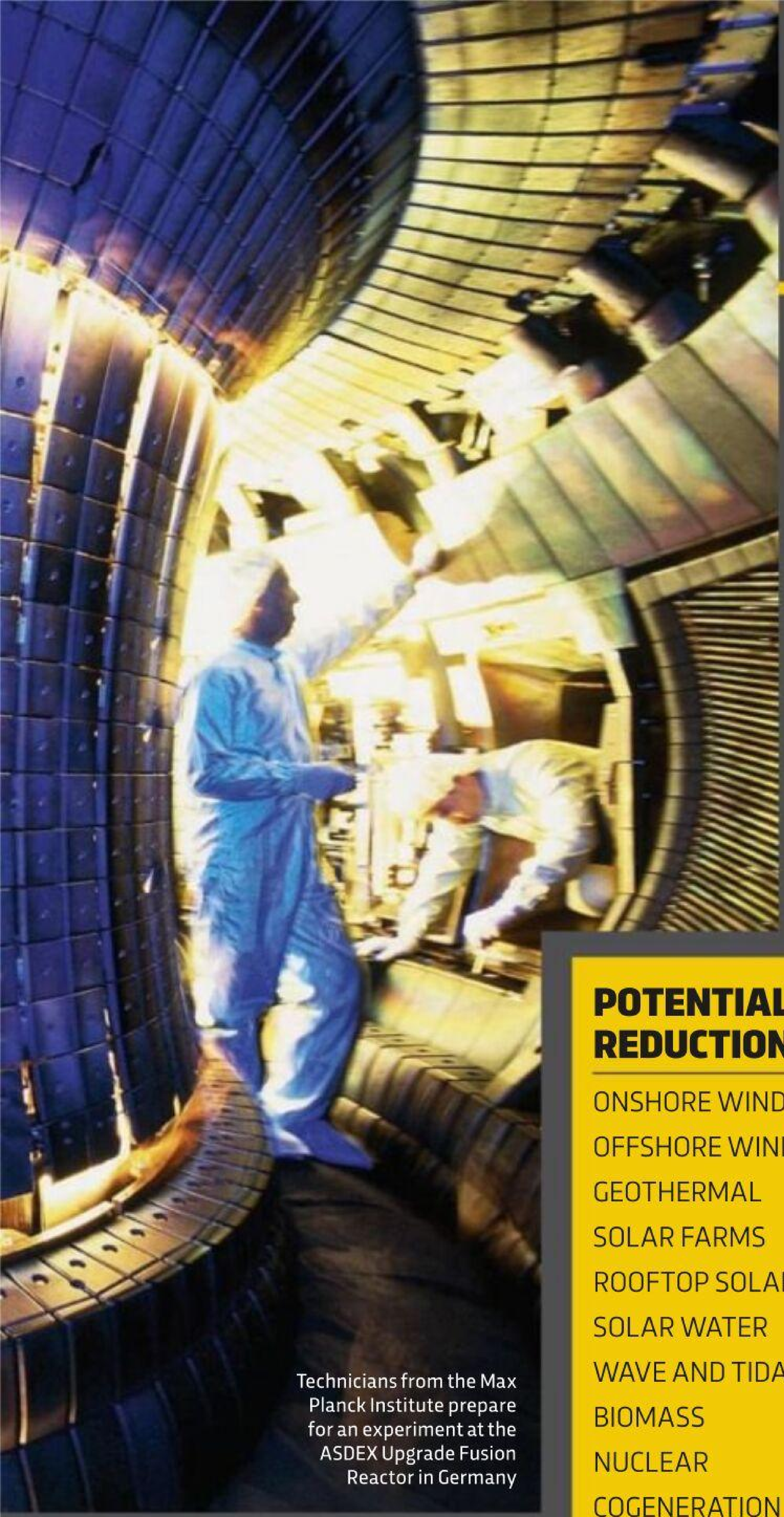
Nuclear power

Near zero-carbon emissions make this an attractive energy source

Nuclear energy has a bad reputation. Fission power plants – where uranium or plutonium atoms are blown apart – produce vast amounts of energy with near-zero carbon emissions. But they're expensive to build, produce dangerous waste products and occasionally melt down with catastrophic consequences.

But there's another type of nuclear fission with none of those drawbacks. Safer and easier to fuel, thorium reactors have been possible for decades. The technology was sidelined during the Cold War, as it cannot easily produce the materials necessary for building nuclear

GETTY X2, GOTEBORG ENERGI



Technicians from the Max Planck Institute prepare for an experiment at the ASDEX Upgrade Fusion Reactor in Germany

weapons. But several countries are now building test reactors, with the first expected to be finished in India in 2018.

But the holy grail of energy production is nuclear fusion. While traditional nuclear power creates energy by splitting atoms, nuclear fusion smashes them together – which happens inside the Sun. The National Ignition Facility in California is forging the way, with another new facility being built in France. While small steps have been made, no-one has succeeded in conquering the ultimate challenge – to generate more energy than is required to start and maintain the reaction. If they can crack that, we'll have access to more clean, green energy than we can ever use.

Cogeneration / district heating

Burning anything from coal to rubbish to generate heat and electricity at the same time

Many communities in Nordic countries burn rubbish for heat and energy. With this system, Sweden achieves a 99 per cent recycling rate, even going as far as to buy rubbish from neighbouring countries to fuel its combined heat-and-power stations. In some cases, these plants have an 80 per cent efficiency, meaning that far less fuel is consumed to produce the same amount of useful energy than traditional power stations. It works across a range of scales, too, from incinerators connected to massive networks of hot-water pipes that power and heat entire cities, to smaller systems that heat a single building and provide electricity. Manhattan's steam system is still used to heat 100,000 buildings, while a few other US towns are using or planning to install similar systems.

POTENTIAL CO_2 REDUCTION BY 2050

ONSHORE WIND	**84.6 gigatons**
OFFSHORE WIND	**15.2 gigatons**
GEOTHERMAL	**16.6 gigatons**
SOLAR FARMS	**36.9 gigatons**
ROOFTOP SOLAR	**24.6 gigatons**
SOLAR WATER	**6.08 gigatons**
WAVE AND TIDAL	**9.2 gigatons**
BIOMASS	**7.5 gigatons**
NUCLEAR	**16.09 gigatons**
COGENERATION	**3.97 gigatons**

SOURCE: Drawdown (Paul Hawken, Penguin, 2017)

Göteborg Energi in Sweden has a 1,000km district heating network, providing heating to more than 90 per cent of all apartment blocks in the area

1 SET UP SOLAR FARMS AT SEA

There's a big push to site solar farms in better locations to make the most of the clean energy offered by the Sun. Solar panels started on the rooftops, then moved into fields, but now developers are constructing them on water. In September 2014, the UK's first floating solar array was built on a reservoir on a Berkshire farm. The 200kW solar panel system will reduce the farm's energy bills as well as slash its carbon emissions.

The opportunities offered by floating solar is especially appealing in countries where land availability is at a premium. Japanese electronics manufacturer Kyocera recently announced plans to build the world's largest floating solar power plant. The installation is to include 11,000 PV panels over two lakes in Japan's Kato City. The sites would be capable of generating 2.9MW of electricity – enough to power nearly 1,000 homes.

2 CONTROL THE RAIN

Drought affects ever larger areas of the planet. But a technology that may bring relief is cloud seeding: using silver iodide particles to help the formation of raindrops. Silver iodide – as well as salt or propane – is said to enhance rainfall. Cloud seeding from planes offers large savings over desalination, which costs around 50 to 60 US cents per cubic metre, according to Prof Zev Levin at the Energy, Environment and Water Research Centre of Cyprus. "If you can prove that it works, it's the cheapest solution, at three cents per cubic metre. It also avoids the need for expensive irrigation systems. The disadvantage is that it cannot be guaranteed to work when and where you want it to," he says.

ALTAEROS ENERGIES, GETTY, NASA, ALAMY

5 MEGA IDEAS TO FIX THE CLIMATE

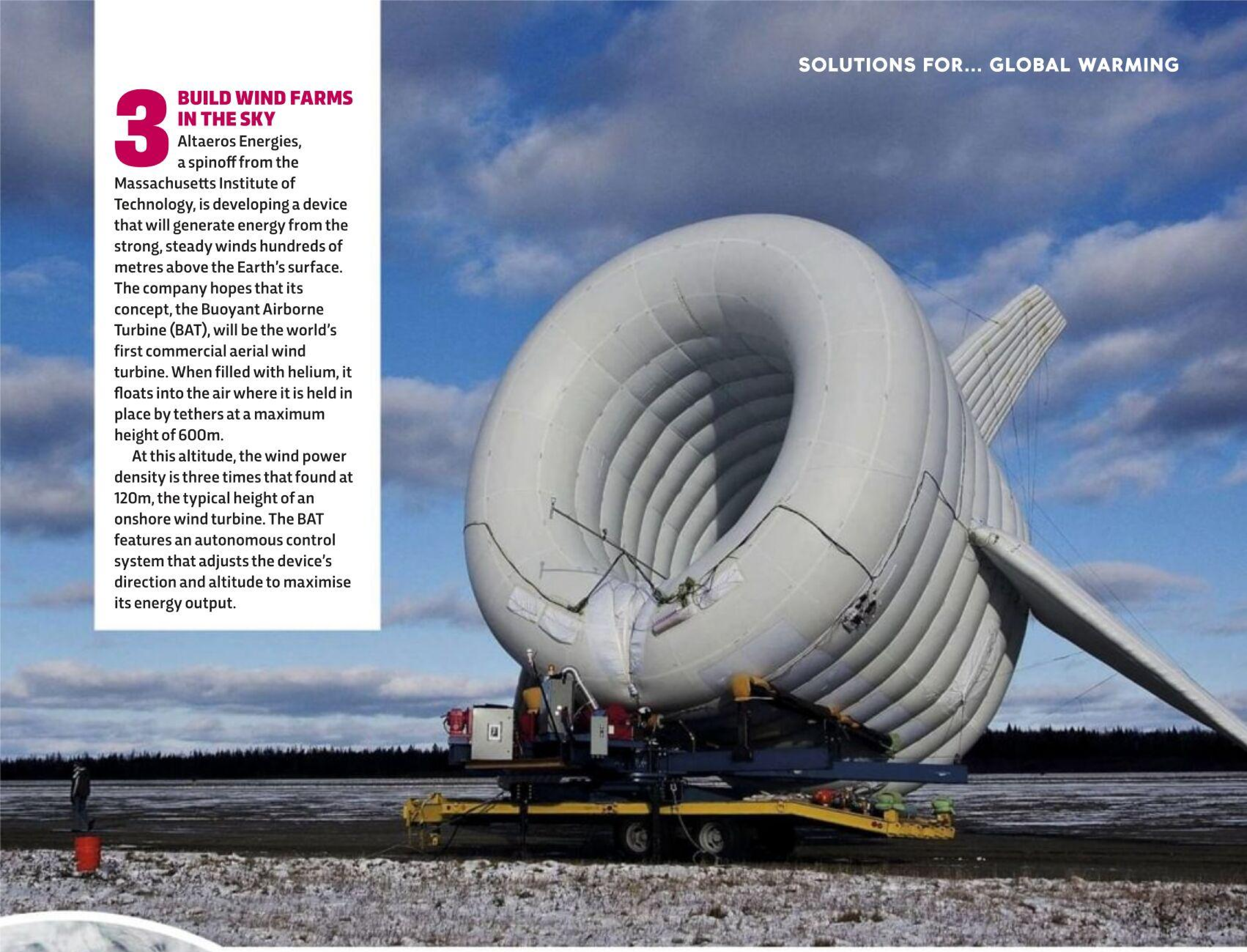
These geoengineering solutions use large-scale technologies to combat global warming

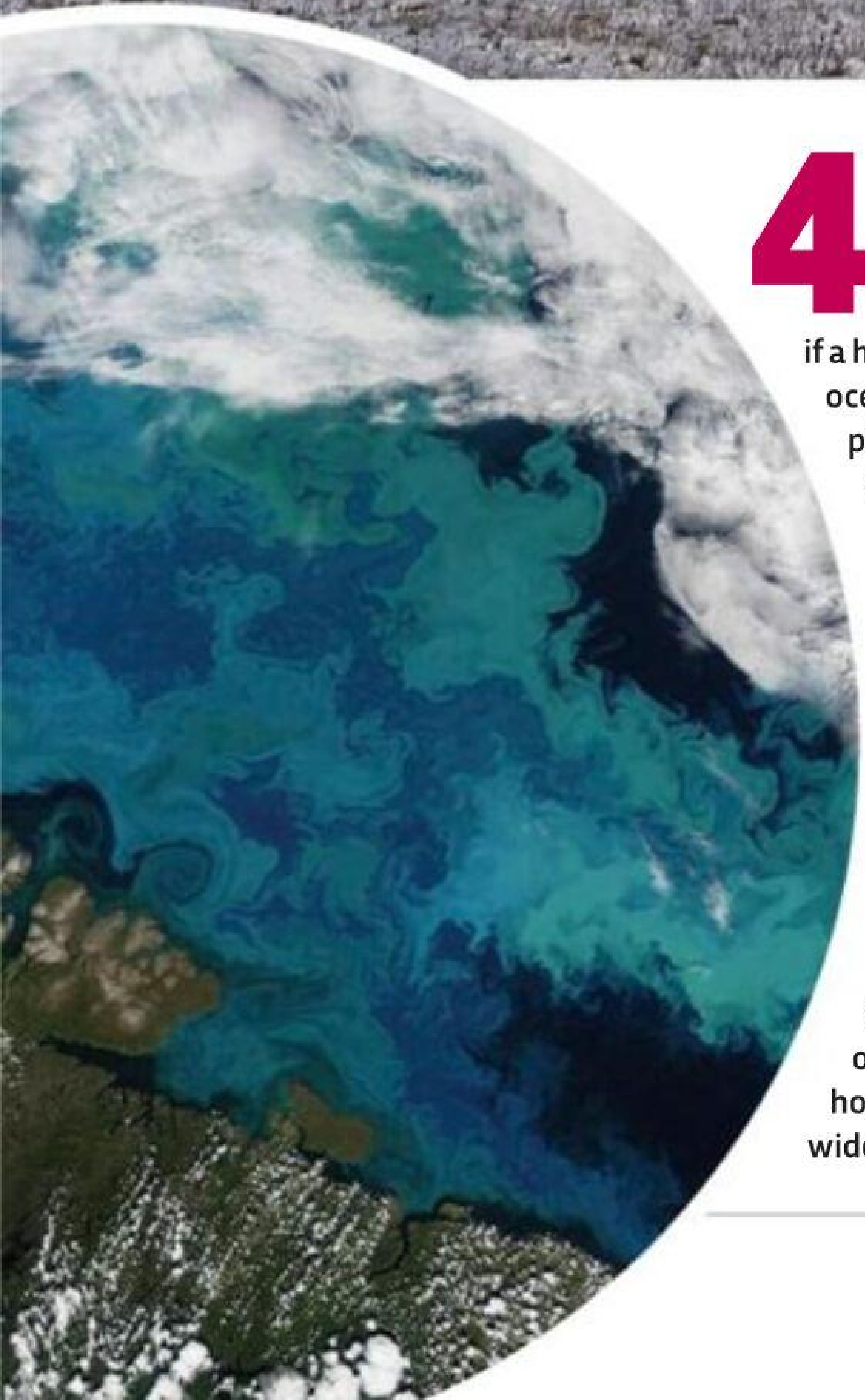
WORDS: **BRIAN CLEGG**

3 BUILD WIND FARMS IN THE SKY

Altaeros Energies, a spinoff from the Massachusetts Institute of Technology, is developing a device that will generate energy from the strong, steady winds hundreds of metres above the Earth's surface. The company hopes that its concept, the Buoyant Airborne Turbine (BAT), will be the world's first commercial aerial wind turbine. When filled with helium, it floats into the air where it is held in place by tethers at a maximum height of 600m.

At this altitude, the wind power density is three times that found at 120m, the typical height of an onshore wind turbine. The BAT features an autonomous control system that adjusts the device's direction and altitude to maximise its energy output.





4 FERTILISE THE OCEANS

In 1988, the late oceanographer John Martin quipped, "Give me a half tanker of iron and I will give you another Ice Age". He said that if a huge amount of iron were dumped into the ocean it would act as a fertiliser and cause plankton growth to increase. During the process of photosynthesis, plankton draw CO_2 from the atmosphere – more plankton would absorb more CO_2, causing a slowing of global warming. Martin's idea caused enough of a storm to kickstart a research effort. "The scientific community hasn't done enough research yet to evaluate iron fertilisation as an effective carbon sequestration option," says Dr Kenneth Coale from Moss Landings Marine Laboratories, California State University. "Whether the carbon would be bound by the plankton for long periods of time remains one of the big questions." Coale is adamant, however, that it would need to be part of a wider strategy for CO_2 reduction and removal.

5 REFLECT SUNLIGHT

There are a couple of ways to reflect sunlight away from Earth and hence cool the planet. The first is to make clouds more reflective. Smaller water droplets lead to a 'whitening' of vapour in the atmosphere, which causes more sunlight to be reflected. By reducing droplet size with cloud seeding techniques, such as spraying seawater solutions from ships, clouds can be brightened to reflect light (see page 68). The alternative is to spray sulphur dioxide or sulphuric acid into the upper atmosphere to form tiny particles that reflect an extra few per cent of incoming solar radiation back into space (see page 62).

BUT WILL THESE BIG CLIMAT

GETTY

IDEAS START A
E WAR?

If we do geoengineer the Earth's climate, could manipulating our weather create political tensions, or even all-out war?

WORDS: CLIVE HAMILTON

Climate change is a problem that shows no sign of going away. According to the authoritative Carbon Action Tracker, even if all nations honour their pledges to cut their greenhouse gas emissions, the globe will still warm by around 3.2°C by 2100 – with catastrophic consequences for humanity and the animal kingdom.

Geoengineering the climate could be a solution. But there are risks, and not just because we're unsure how effective these interventions would be. What if geoengineering causes more problems than it solves? Could one country's efforts to solve its climate problem inadvertently mess up the weather elsewhere? And ultimately, could we be looking at the dawn of a new kind of war – one fuelled by a battle for dominance over our planet's climate system?

The greatest hurdle for geoengineering schemes lies not in getting carbon out of the atmosphere, which is not so hard, but finding somewhere to store the huge quantities permanently. The deep ocean offers one possible solution, but we still don't have a feasible method of doing this.

Some proposals are relatively benign, but also relatively ineffective. The technology receiving most attention – and the one most likely to be deployed because it's cheap and feasible – is sulphate aerosol spraying. The idea is to spray sulphur dioxide or sulphuric acid into the stratosphere or upper atmosphere to form tiny particles that reflect an extra one, two or three per cent of incoming solar radiation back into space. This cools the planet in the way that large volcanic eruptions are known to do for a couple of years.

In effect, humans would install a radiative shield between the Earth and the Sun: one that could be adjusted by those who control it to regulate the temperature of the planet. The models indicate that if we reduced the amount of sunlight reaching the planet, the Earth would indeed cool fairly quickly, although with less effect at the poles.

Solar geoengineering could suppress monsoon rains, affecting food supplies for many millions of people

A 2010 study published in *Nature Geoscience* found that, under a solar geoengineering regime, differences in climate response across large regions, including countries like China and India, would be exacerbated, making consensus about how much to reduce incoming solar radiation "difficult, if not impossible".

Some atmospheric scientists, like Alan Robock at Rutgers University, argue that the complexity of the climate system means that it's difficult to draw any firm conclusions about the consequences of such a radical intervention in the Earth system. They point out that the chemistry of the upper atmosphere – including the ozone layer – is complicated and poorly understood. Reducing the amount of sunlight reaching the Earth in a computer model may give little clue as to what would happen in the actual climate system if a layer of sulphate aerosols were injected into it.

One worry is that, combined with increased water vapour as a result of warming, adding sulphates to the upper atmosphere could be a "lethal cocktail" for ozone loss. Other studies indicate that, depending on the kind of aerosol spraying program, the South Asian and East Asian monsoons could be disrupted. Tropical rainfall depends on differences between temperatures on land and sea, and some models show that by changing the temperature ratio between land and sea, solar geoengineering could suppress monsoon rains, affecting food supplies for many millions of people.

However, global warming itself is changing precipitation patterns around the world (broadly speaking, dry regions are becoming dryer and wet ones wetter) so a solar shield may improve rainfall in some regions that are drying out. It's here we get to some of the most vexed issues associated with geoengineering.

UNKNOWN UNKNOWNS

If the most sophisticated models cannot provide a firm answer to the question of how solar geoengineering would affect the global climate, nor can experiments, only full-scale implementation would provide a clear idea.

Even then, we would need at least 10 years of global climate data before we had enough information to separate out the effects of sulphate aerosol spraying from natural climate variability and, indeed, from the effects of human-induced climate change. The levels of omniscience and omnipotence required to make it work seem to be beyond the powers of mere mortals.

ABOVE: Emissions from industry, such as steel manufacturers, contributes enormously to global warming

LEFT: Biochar has been seen as a potential solution for reducing carbon dioxide in the atmosphere by locking away the carbon in the soil

GETTY X2

Large volcanic eruptions can cool the planet by preventing a little solar radiation from reaching us. Some geoengineering schemes work in a similar way

To compound the risks, if after 10 years we had accumulated enough data to decide that our intervention was not a good idea, it may be impossible to terminate the solar shield.

For some time, ecologists have known that the *rate* at which the globe warms is a greater threat to ecosystems than the *amount* of warming, because a slower rate of warming gives plant and animal communities more time to adapt. If the solar shield causes some nasty unintended effects (including conflict between nations), removing it suddenly would cause the suppressed warming to 'rebound'. It's been estimated that if warming occurs at a rate of 0.3°C per decade (well within the estimated rebound range) then only 30 per cent of the globe's ecosystems could adapt and survive.

So we may find that, once deployed, removing the shield becomes too risky; we'd be stuck with it. The danger would be multiplied if we failed to take the opportunity to cut greenhouse gas emissions sharply while the shield was in place. This is perhaps the greatest hazard of going down this path.

Some technologies are inherently political in the sense that they increase the power of those who control it and reduce the power of those excluded from it. It's not hard to picture how power might be reallocated within and between nations if a technology to regulate the global climate were deployed.

Paradoxically, solar geoengineering can also be seen as a means of *preserving* existing social

Some experts believe that climate change-induced drought, high food prices and migration nudged Syria into civil war

and political structures that are threatened by measures to cut carbon emissions. Instead of taxing fossil fuels and restricting air transport, those profiting from these activities, and their political supporters, might welcome a technofix like sulphate aerosol spraying.

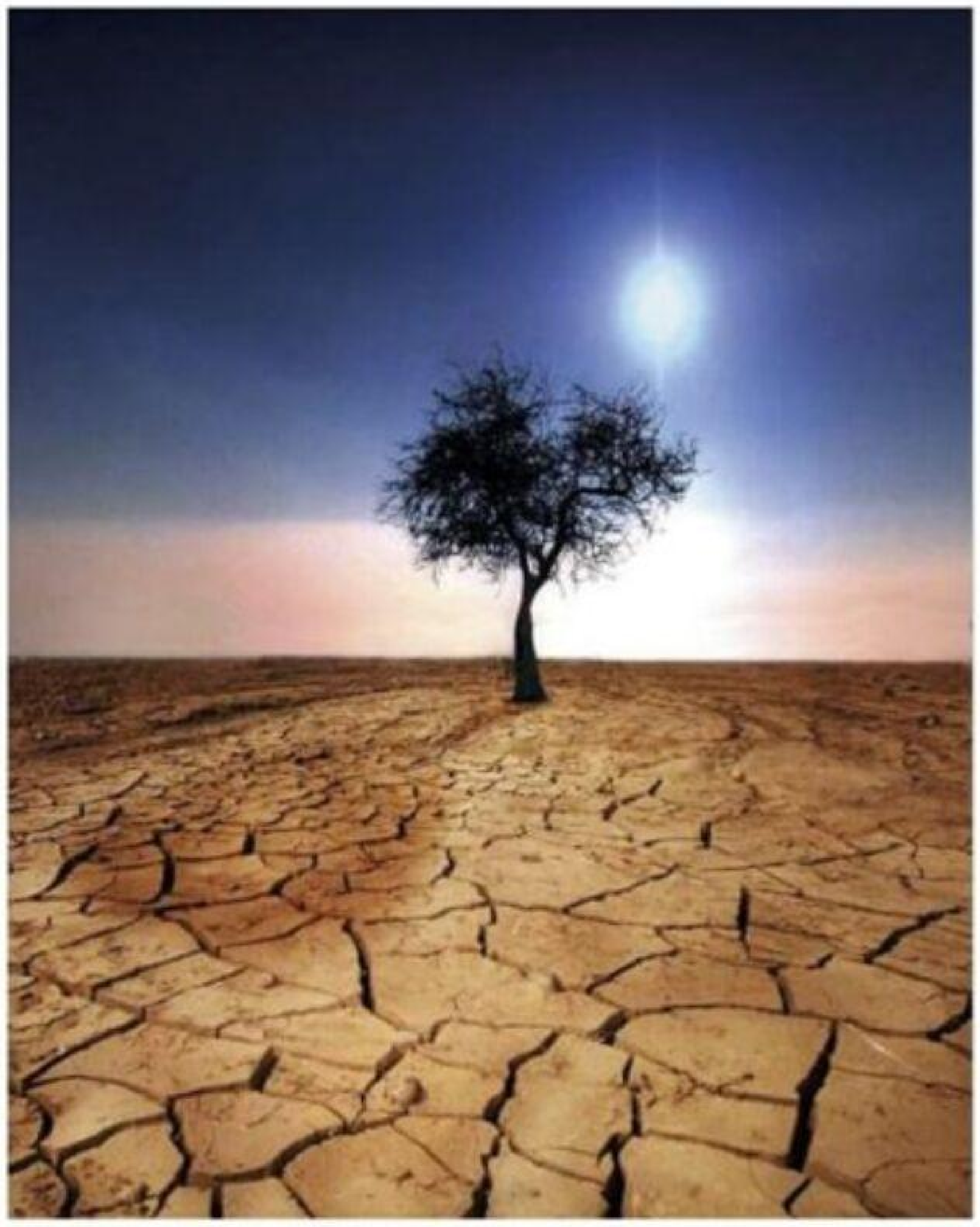
Indeed, in the US, conservative think tanks that have been at the forefront of climate science denial have shown interest in solar geoengineering. It's cheap and protects vested interests. Geoengineering promises to turn a drastic failure of the free enterprise system into a triumph of human ingenuity.

At a deeper level, the implicitly autocratic nature of global climate regulation has an appeal to those on the political right just as it frightens those on the democratic left. It's hard to imagine a government in charge of a solar geoengineering project holding a referendum on whether the Earth's temperature should be reduced by one degree or two.

The control of the Earth's weather could become the responsibility of a kind of 'Climate Regulation Agency', staffed by a technocratic elite whose task would be to continuously collect a vast array of weather information, feed it into data systems, separate out the effects of the solar shield from other factors, and advise the relevant department as to how many planes loaded with sulphur dioxide should be sent up next week and where they should dump their loads.

CLIMATE WARS

Military planners around the world recognise climate change as a 'threat multiplier'. US Defence Chiefs, among others, have incorporated a changing climate into their military planning and equipment supply. Climate change is expected to create political instability; indeed, some experts believe that climate change-induced drought, high food prices and migration to cities nudged Syria into civil war. ➜



LEFT: Global warming is changing precipitation patterns around the world, making dry regions dryer and wet regions wetter

BELOW: Countries such as India and Pakistan rely on the monsoon season, without the rains famine could occur

GETTY X3

A dictator with his or her hand on the global thermostat is a scary prospect

Last year, President Trump announced that the US would be withdrawing from the Paris Agreement on climate change

GETTY

If that's true – and we can only guess at how much conflict there might be in a world 3°C warmer – mitigating warming by geoengineering ought to create a more peaceful world. But it's not so straightforward.

When hit by a devastating flood, drought or storm, a community will tend to see it as an act of God – a natural event that it just has to cope with. But what if we believed that the death and destruction were caused not by indifferent nature but by someone manipulating the weather?

If a nation had embarked on a system-altering form of climate engineering like sulphur dioxide spraying, it would be virtually impossible to work out whether an extreme weather event somewhere in the world was due to natural variability, human-induced climate change or climate manipulation. And climate manipulation would quite likely get the blame.

The government of China, faced with a catastrophic drought in the north of the country, might decide its survival demands rapid global cooling. But sending up the planes to spray sulphur dioxide might deprive India and Pakistan of their monsoon rains, bringing on famine. Three nuclear-armed nations would then be in conflict over weather patterns that affect the survival of millions of their citizens.

It's hard to know who might first be tempted to regulate the global climate. Given the severe environmental and geopolitical risks, and the deep ethical divide over whether humans should 'play God', governments in democratic countries may be hamstrung. Authoritarian leaders who do not need public approval to act may have a freer hand. Do we want Vladimir Putin or Xi Jinping controlling our weather? A dictator with his or her hand on the global thermostat is a scary prospect. But imagine if several poor nations (let's say Bangladesh, Tuvalu, the Maldives and Ethiopia) clubbed together and sent up a fleet of planes to spray sulphur dioxide.

Now the moral calculus leaves us uncertain what to think. Don't they have the right to save themselves from an existential threat, even if by risky means?

Reaching a consensus to regulate Planet Earth's climate would, in the words of a 2013 study, "pose immense challenges to liberal democratic politics".

In the circumstances, the only acceptable answer is a global agreement to regulate research into geoengineering. If it ever comes to deployment, conflict could be avoided only if an inclusive international institution makes the decision. Without it, one nation would control the climate of others, and those others will be tempted to engage in their own 'counter-geoengineering'. And then we really are in trouble.

Clive Hamilton is professor of public ethics at Charles Sturt University in Canberra and the author of *Earthmasters: The dawn of the age of climate engineering.*

AN ALTERNATIVE VIEW

***Peter Irvine** is a climate scientist at Harvard University who researches solar geoengineering. He argues that the benefits of the technology could outweigh the risks*

I've been working since 2009 to understand the potential and limits of geoengineering. Clive Hamilton paints a picture of this technology that I simply do not recognise.

To address climate change, carbon dioxide emissions will have to be driven to zero, but however fast emissions are cut, the climate will still warm considerably over the 21st Century. It's here that stratospheric aerosol geoengineering could prove an extremely useful tool.

Reducing temperatures will reduce the risks posed by climate change, and our work has shown that it doesn't make much difference whether this is done by lowering emissions or by cooling from solar geoengineering. This doesn't mean geoengineering should be a replacement for emissions cuts – indeed, it may introduce some new risks of its own – but it would certainly help to offset some of climate change's worst impacts.

Clive points to the potential dangers of geoengineering reducing monsoon rainfall, but his picture is incomplete. Water availability depends not only on how much rain falls but also on how quickly it evaporates in the heat of the day. The same climate models that show that geoengineering would reduce rainfall also show that it would reduce evaporation, potentially leading to more, not less, water availability.

> IT WOULD HELP TO OFFSET SOME OF CLIMATE CHANGES' WORST IMPACTS

Clive also claims that, because climate control would require technical knowledge, it would lead to the technocrats taking over. Yet our lives depend on the technocrats who manage our electricity grids, our water supply and our transport systems, and still our societies remain robustly democratic.

Clive portrays geoengineering as an idea born of cold-war hubris and pushed by right-wing climate deniers; I instead see a well-intentioned proposal that is being critically evaluated by hundreds of researchers around the world, from disciplines as diverse as engineering, economics and international law. Rather than coming from shadowy right-wing think tanks of fossil-fuel interests, funding for geoengineering research comes mostly from government funding and environmentally-minded philanthropists.

Outside of academia, there are also exciting developments. The Solar Radiation Management Governance Initiative is an international NGO that's working to empower scientists and policy makers in developing countries to engage with geoengineering, while in New York, the Carnegie Climate Geoengineering Governance Initiative aims to bring this topic to the attention of international policy makers at the UN.

The ratification of the Paris Agreement and the stunning developments in solar and wind power in recent years show that the world has the will and is developing the tools to tackle climate change. Even so, international cooperation in this area remains a notoriously difficult process.

For geoengineering, the picture is completely different. The costs of geoengineering are low, its effects will be felt quickly, and they'll be global in scope. This means that governments will have a real incentive to work together to realise the potential benefits of geoengineering.

HAVE YOUR SAY

Who do you agree with? Get in touch on our Twitter page **@sciencefocus**, or send an email to **reply@sciencefocus.com**

THE CLOUD CHASER

*If we learn how to influence the weather, **climate change** could be slowed. **Anna Possner** is crunching the numbers to find out what the consequences might be*

We see them almost every day, but there's a lot we don't know about clouds. Even to meteorologists, their inner workings are somewhat hazy. And that matters, because clouds play an important role in regulating the planet's temperature – both reflecting radiation from the Sun and acting like a blanket, keeping the Earth's heat in. In fact, some clouds are so effective at the reflecting bit that 'supercharging' them by making them even brighter and whiter has been suggested as a way to reduce temperatures and fight global warming (see page 59).

It's an idea that atmospheric scientist Anna Possner is familiar with. Her research at the Carnegie Institution for Science in Stanford, California, will help to answer the question of whether 'cloud brightening' might actually work. She's part of the Marine Cloud Brightening Project, an initiative that's brought together cloud experts in the US and UK with retired Silicon Valley engineers to find out whether spraying tiny droplets of seawater into clouds can brighten them enough to cool the planet – and do so without any nasty side effects.

> **"Could spraying tiny droplets of seawater into clouds brighten them enough to cool the planet – without nasty side effects?"**

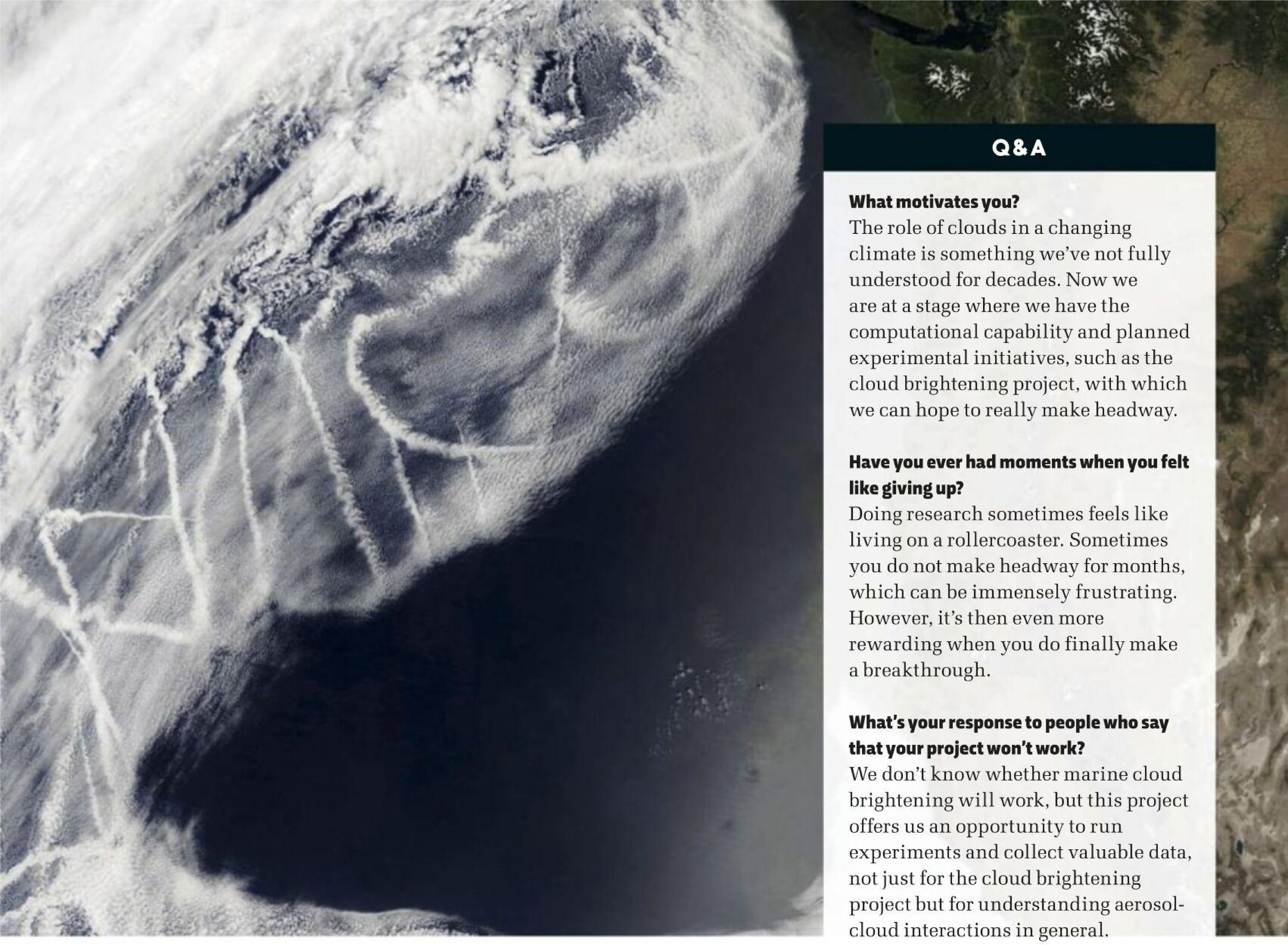
Possner carries out experiments with clouds, looking to see what happens when she injects droplets of seawater into them. But the clouds Possner works with are made up of numbers – they are numerical representations of the real thing created using algorithms that model how atmospheric systems work. So complex are these models that they require supercomputers, such as those at the National Center for Atmospheric Research in Wyoming, to run. "You run your models and you get output files that are usually four-dimensional – time and 3D space of various fields such as temperature, pressure, cloud water and cloud reflectivity," says Possner.

It was Possner's research for her PhD at ETH Zurich, Switzerland, that led to cloud brightening. There she studied ship tracks – the shipping equivalent of aircraft contrails. These slender strips of brightened cloud form as ships crossing oceans belch out tiny aerosols, such as sulphate particles, from their smoke stacks. It's around these tiny particles that water vapour in the atmosphere condenses, making the clouds more reflective. It's exactly the same principle behind cloud brightening, except the particles that would supercharge the clouds would be salt water.

Cloud brightening, like most geoengineering projects, is controversial. The biggest concern being that meddling with our weather systems might have unforeseen effects that could make things worse. This controversy makes funding for such research hard to come by. It also makes young atmospheric scientists like 30-year-old Possner tentative about getting involved. "I'm not saying I support it or I'm against it really, we've just got to start this now in terms of research. This is an idea that's out there, and if people expect the scientific community to make a qualified statement about the possibilities and limitations of this method, it requires coordinated research."

Possner's virtual clouds are helping to plan the next stage of the project – where seawater will be sprayed into real clouds, rather than numerical ones. At first, the plan is to run experiments on land at Moss Landing on the Californian coast before starting trials out at sea. Exactly when these experiments will happen is dependent on funding. "If you want to see whether this will work, you've got to test it in the field," says Possner. "That's where marine cloud brightening has a benefit – you can test it in the small scale without it having a long-term impact. Sea salt sediments out of the atmosphere quickly and you're not spraying anything that isn't there already."

CARNEGIE INSTITUTION FOR SCIENCE ILLUSTRATION: MARIO WAGNER

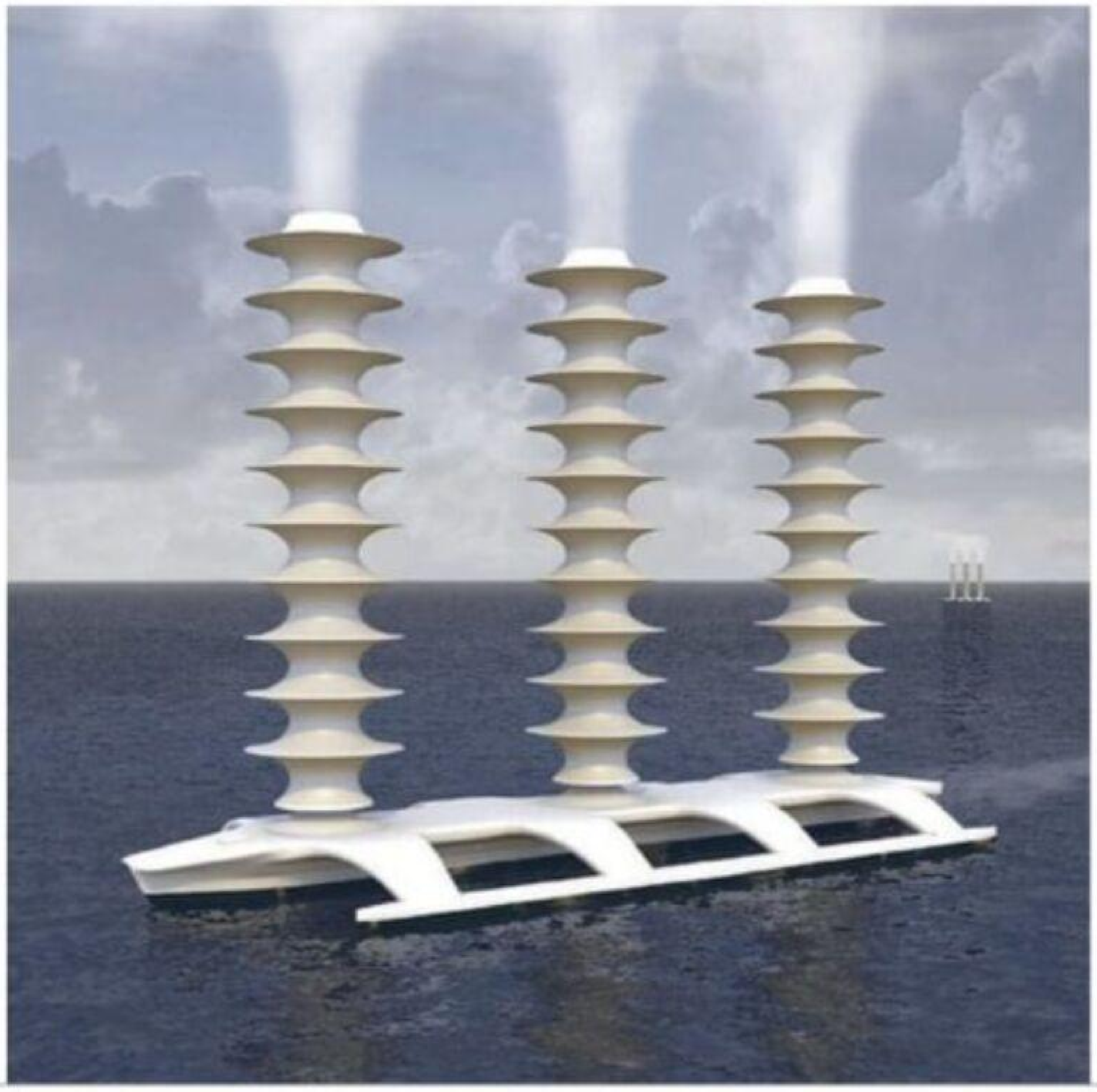


Q&A

What motivates you?
The role of clouds in a changing climate is something we've not fully understood for decades. Now we are at a stage where we have the computational capability and planned experimental initiatives, such as the cloud brightening project, with which we can hope to really make headway.

Have you ever had moments when you felt like giving up?
Doing research sometimes feels like living on a rollercoaster. Sometimes you do not make headway for months, which can be immensely frustrating. However, it's then even more rewarding when you do finally make a breakthrough.

What's your response to people who say that your project won't work?
We don't know whether marine cloud brightening will work, but this project offers us an opportunity to run experiments and collect valuable data, not just for the cloud brightening project but for understanding aerosol-cloud interactions in general.



ABOVE: The tracks in these clouds are caused by tiny particles that have been released from ships. Water vapour condenses around the particles, making the clouds brighter

LEFT: Concept art of a yacht that would spray seawater into clouds to make them brighter

Where do you see the planet in 30 years?
I'd like to see a really consolidated effort to move from fossil fuels to low carbon alternatives that are economically competitive, and I'd also like to see more hybrid cars on the road, if not electric.

What will your field of research look like in the year 2050?
It's a really exciting time in climate modelling. We've started moving away from modelling individual regions over short time periods. In the future, we'll be able to model the entire Earth at kilometre, or even sub-kilometre, resolution [the distance between the data points within the model] over long periods, which will hugely improve the accuracy of our climate predictions.

ALAMY, JOHN MACNEILL, GEORGIA INSTITUTE OF TECHNOLOGY, SCIENCE PHOTO LIBRARY

HOW IT WORKS

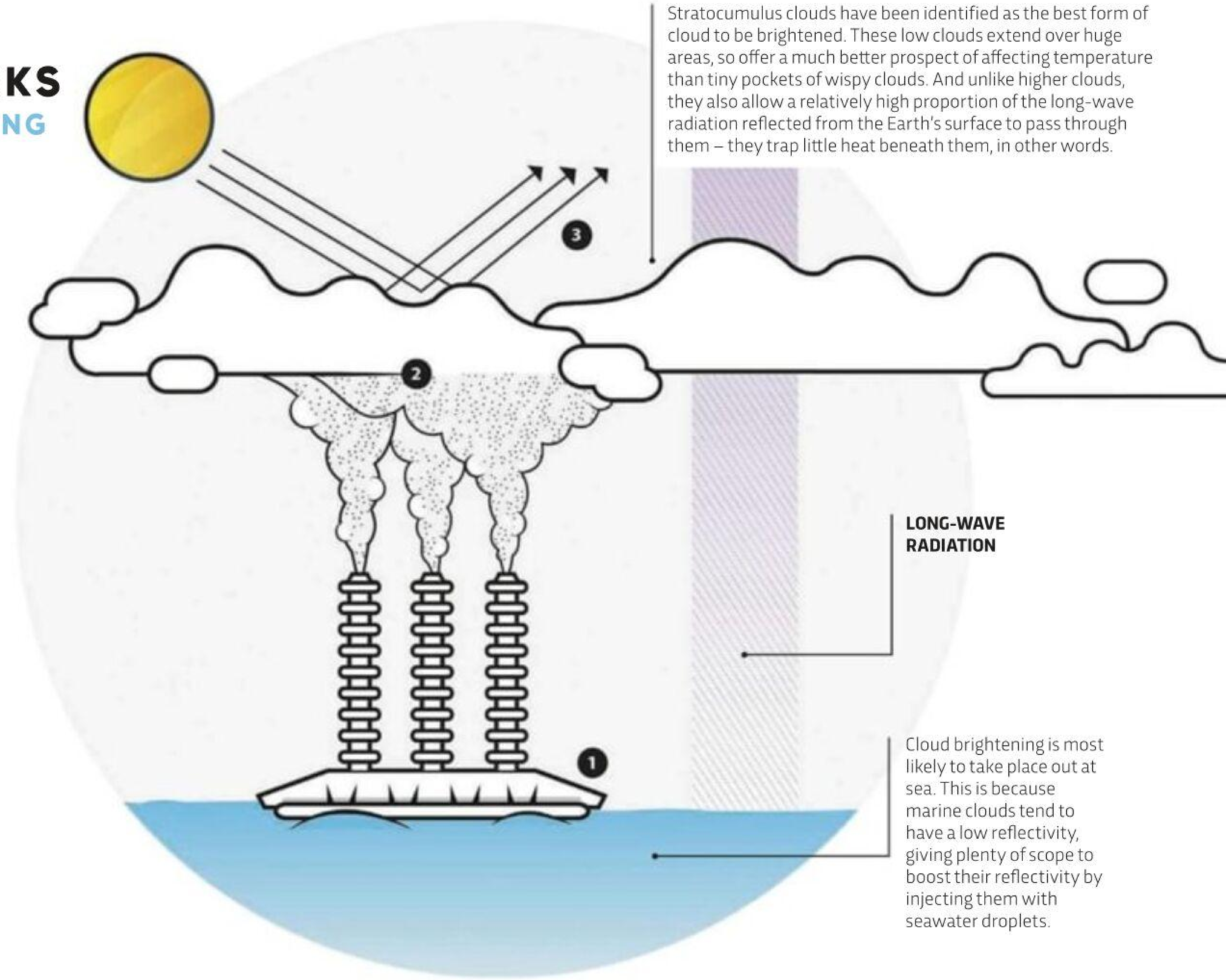
CLOUD BRIGHTENING

Clouds sprayed with seawater reflect more sunlight, which could help reduce the planet's temperature.

① Nozzles on board a ship pump tiny particles of seawater into the air. The nozzle already developed by Marine Cloud Brightening Project engineers is capable of generating three trillion particles a second.

② When the seawater particles reach the clouds, water vapour condenses around them. The water droplets they form in the clouds are small, resulting in more scattering of incoming light because there are more surfaces for the light to reflect off.

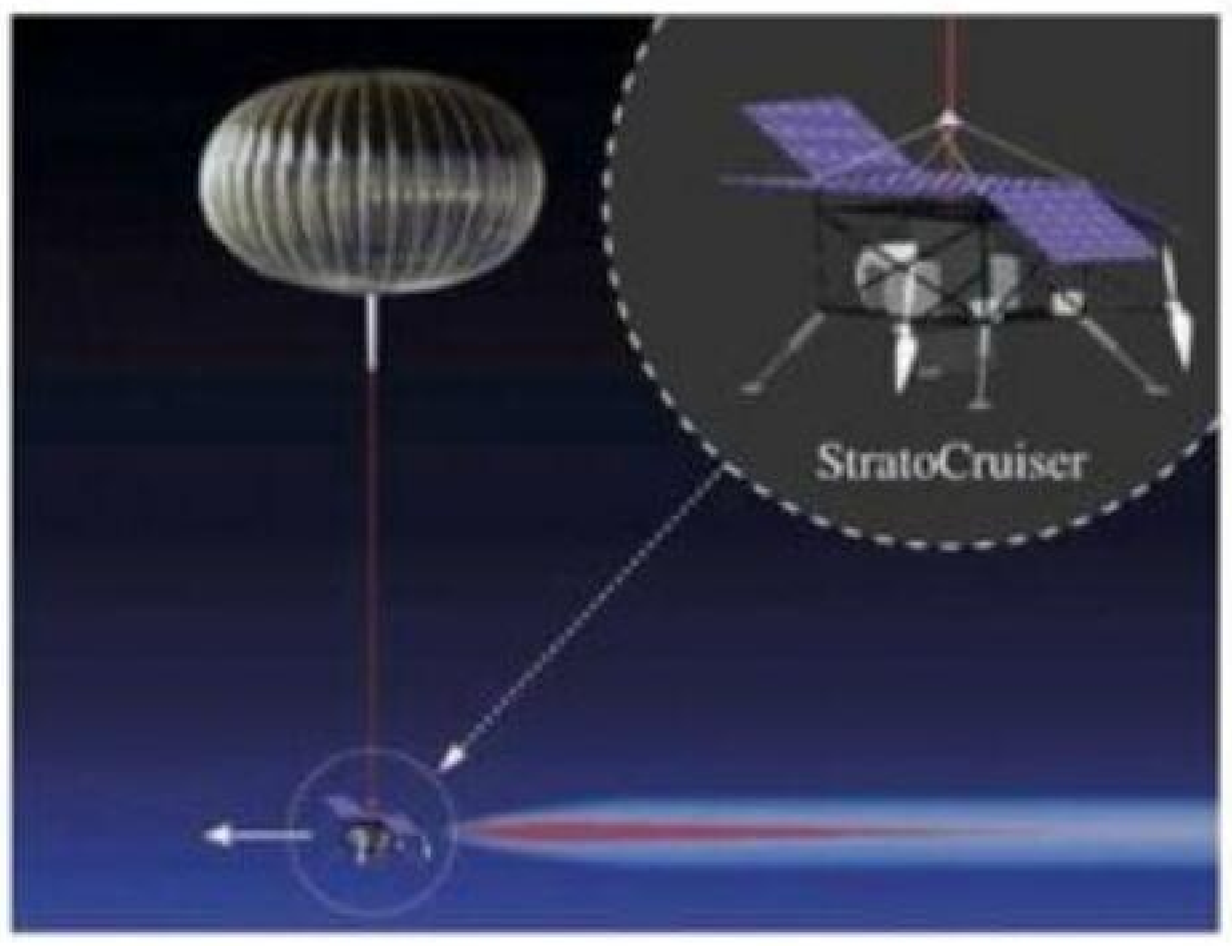
③ A higher proportion of shortwave radiation from the Sun is reflected by the clouds that have been brightened. This reduces temperatures at the sea surface.



Stratocumulus clouds have been identified as the best form of cloud to be brightened. These low clouds extend over huge areas, so offer a much better prospect of affecting temperature than tiny pockets of wispy clouds. And unlike higher clouds, they also allow a relatively high proportion of the long-wave radiation reflected from the Earth's surface to pass through them – they trap little heat beneath them, in other words.

Cloud brightening is most likely to take place out at sea. This is because marine clouds tend to have a low reflectivity, giving plenty of scope to boost their reflectivity by injecting them with seawater droplets.

CLIMATE CONDITIONERS

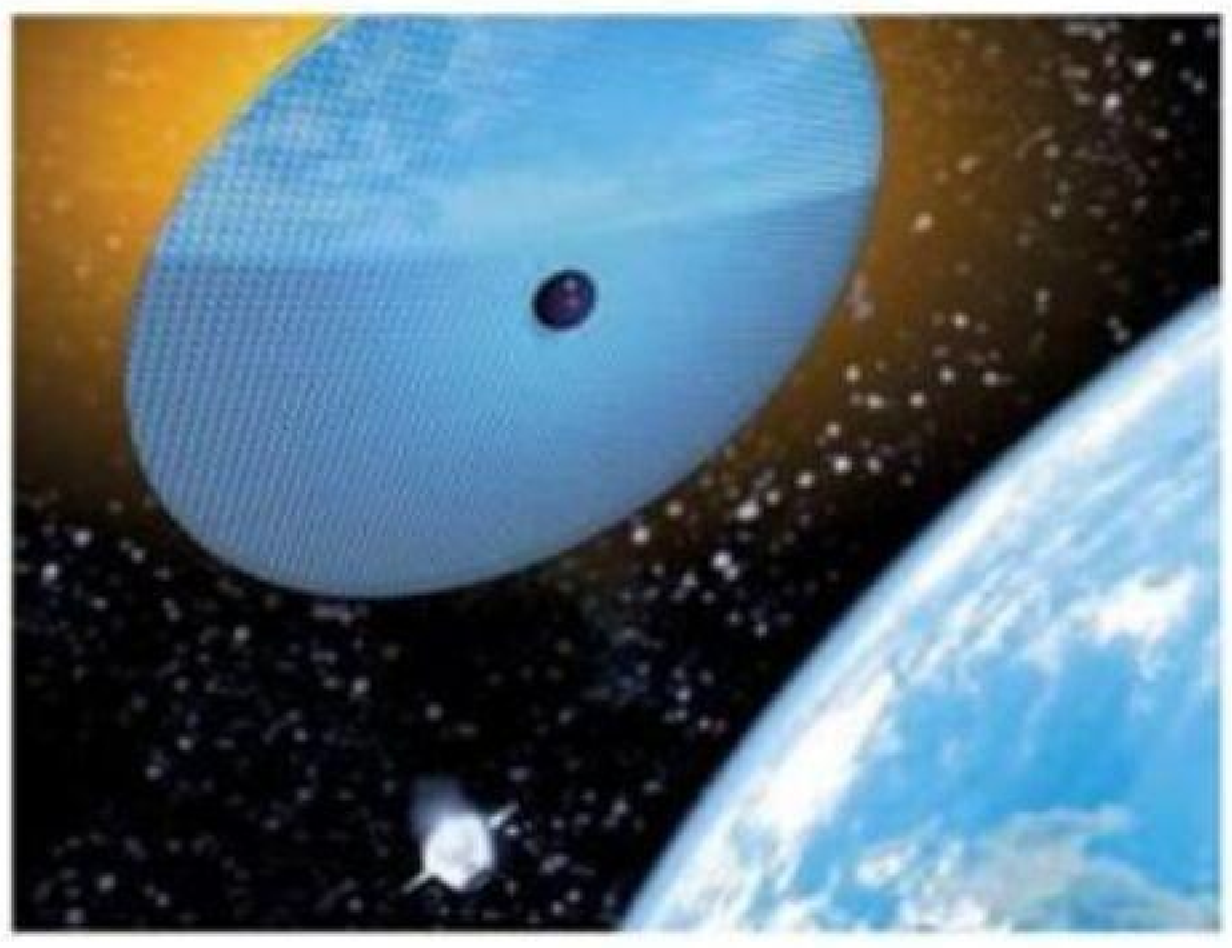


SUPERCHARGE THE STRATOSPHERE

Instead of making clouds brighter, another idea is to release particles into the atmosphere that can reflect the Sun's radiation. At some point in 2018 Harvard professors David Keith and Frank Keutsch are expected to launch a high-altitude balloon 20km into the air above Tucson, Arizona, and spray a small quantity of calcium carbonate particles to see what happens.

OCEAN SEEDING

"Give me half a tanker of iron and I'll give you an ice age," said the late oceanographer John Martin in 1988. Although he was half joking, Martin stood by his idea of using iron to boost plankton and increase the carbon dioxide absorbed from the atmosphere. Tests have been carried out but it's not yet clear how much of the plankton sinks to the seabed and locks the carbon away.



SPACE REFLECTORS

It sounds implausible – place a giant reflective sunshade in space to block off some of the sunlight that reaches Earth. But this idea has been receiving some consideration: in a report by the Royal Society, it was suggested that in the long-term, a space sunshade may be cheaper and safer than geoengineering the stratosphere. Tests are currently confined to modelling various approaches.

ILLUSTRATION: ACUTE GRAPHICS

A BREATH OF FRESH AIR

As airborne pollution rises in cities around the world, millions of lives are increasingly at risk. Last year, Athens, Mexico City, Paris and Madrid announced diesel vehicles will be banned in their cities from 2025. So what effect do diesel emissions have on our health, and what are the solutions to air pollution?

WORDS: **ROBERT MATTHEWS**

The Chinese capital Beijing often suffers from severe air pollution

GETTY

You know there's a problem when the giants cough up. Panasonic have started paying employees to relocate to Beijing, because the city's air quality is so bad. And it's not just the capital that's smothered in smog. China has promised $277 billion to deal with the problem in cities across the country. Face masks have become a fashion necessity for Chinese urbanites. The police have even been issued with nose plugs to keep the pollutants out. But these are short-term measures. How is the rest of the world going to tackle this dangerous problem? Fortunately, scientists are working to clear the air.

While the dense 'pea-souper' smogs of the 1950s may have gone for good, they have been replaced by invisible forms of pollution that build up on bright, still days. Exactly how such pollutants affect our health is the subject of urgent research, but there's growing concern that they pose a major health threat. Air pollution is back at the top of the UK public health agenda, implicated in the deaths of tens of thousands of people each year.

According to Prof Dame Sally Davies, chief medical officer for England, it's already clear that the elderly and those with pre-existing heart disease or lung disorders are particularly at risk. "However, researchers are finding that air pollution may be associated with a much wider range of health conditions," she says. These include diabetes and neurological disease. Unborn babies can even be affected.

Davies is one of many leading health experts now calling for action. Last year, the National Institute for Health and Care Excellence (NICE) unveiled draft proposals on how to tackle the issue, following legal action against the UK government, which has been found to be in breach of European standards for air quality.

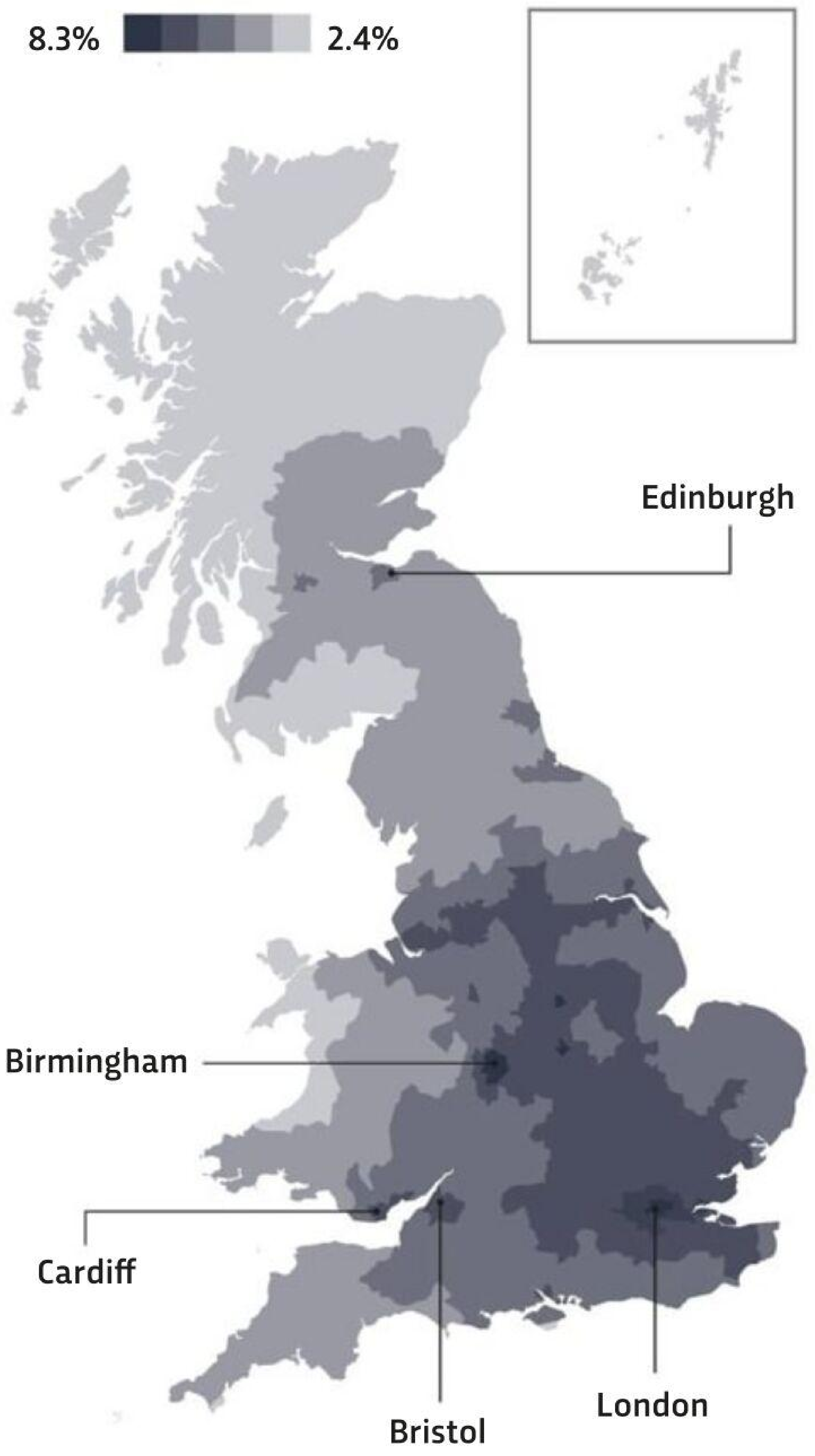
> While the dense smogs of the 1950s have gone, they've been replaced by invisible pollution

The renewed public concern has been sparked by the scandal around diesel cars built by Volkswagen. In 2015, the US Environmental Protection Agency (EPA) revealed that the car manufacturer had fitted its vehicles with tech that sensed when the car was undergoing an emissions test, and altered its performance to ensure compliance. But once on the road, the car reverted to its normal performance – and far higher emissions of oxides of nitrogen (NOx), one of the pollutants now prompting concern. Yet the scandal came as little surprise to air quality experts. According to Prof Alastair Lewis of the University of York, scientists had expected NOx levels to be declining in city centres as old vehicles were replaced by new,

DEATHS FROM AIR POLLUTION IN YOUR REGION

*On this map, you can see the estimated percentages of adult deaths attributable to particulate air pollution**

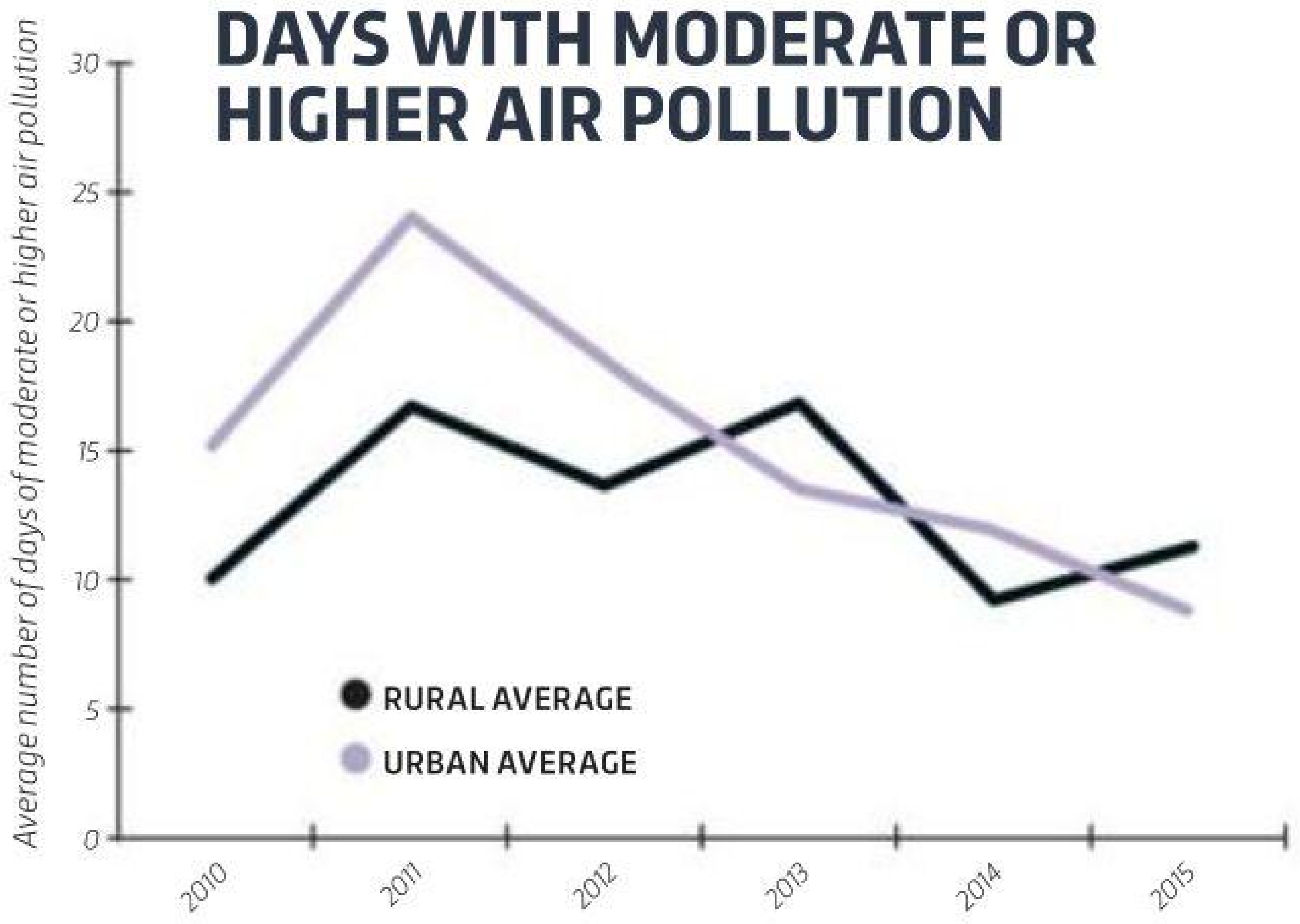
DATA SOURCES: PUBLIC HEALTH ENGLAND AND DEFRA



*Data as of 2017. Does not include deaths from other forms of air pollution

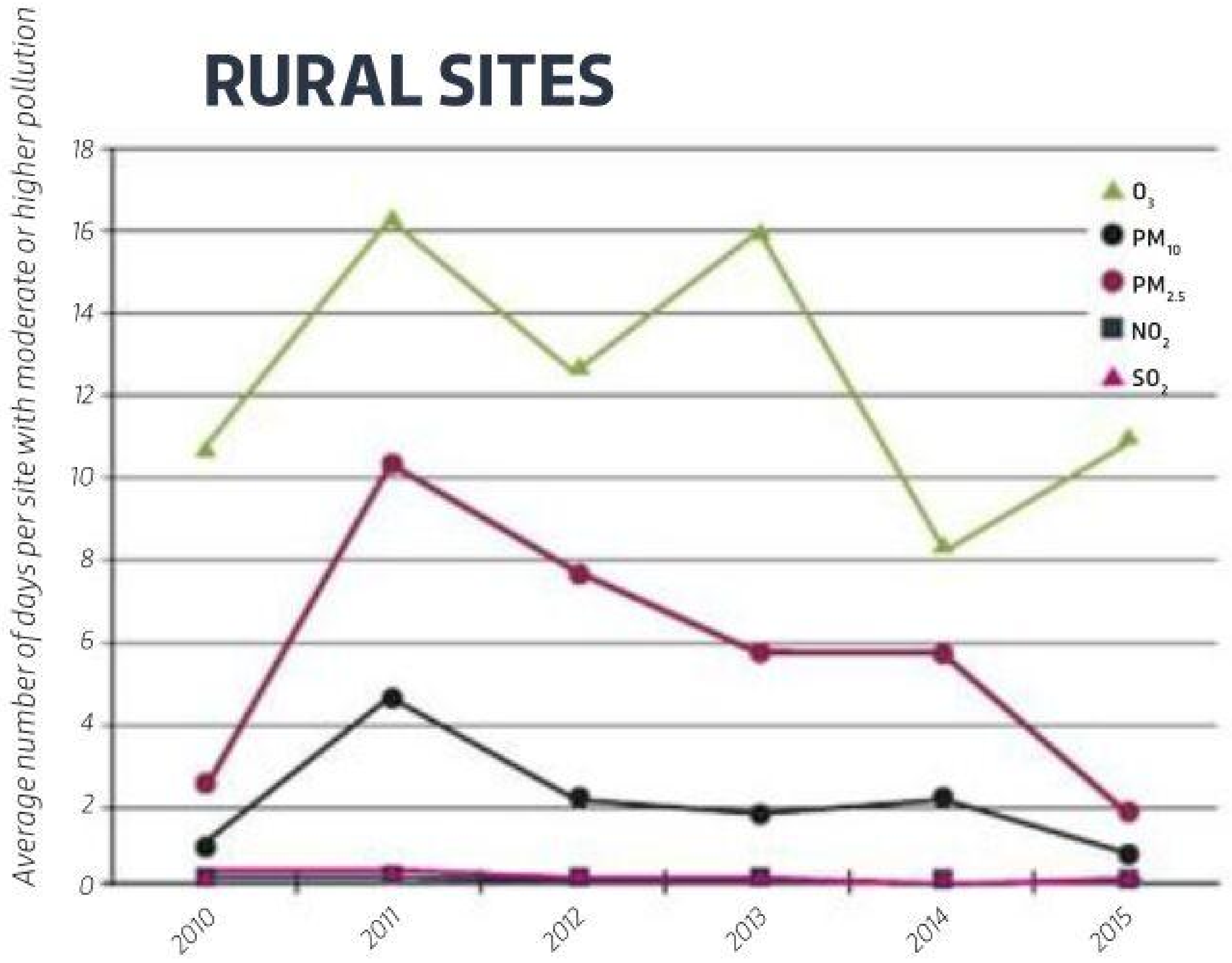
Levels of air pollution are declining, but experts are concerned it's not falling as quickly as expected

DAYS WITH MODERATE OR HIGHER AIR POLLUTION



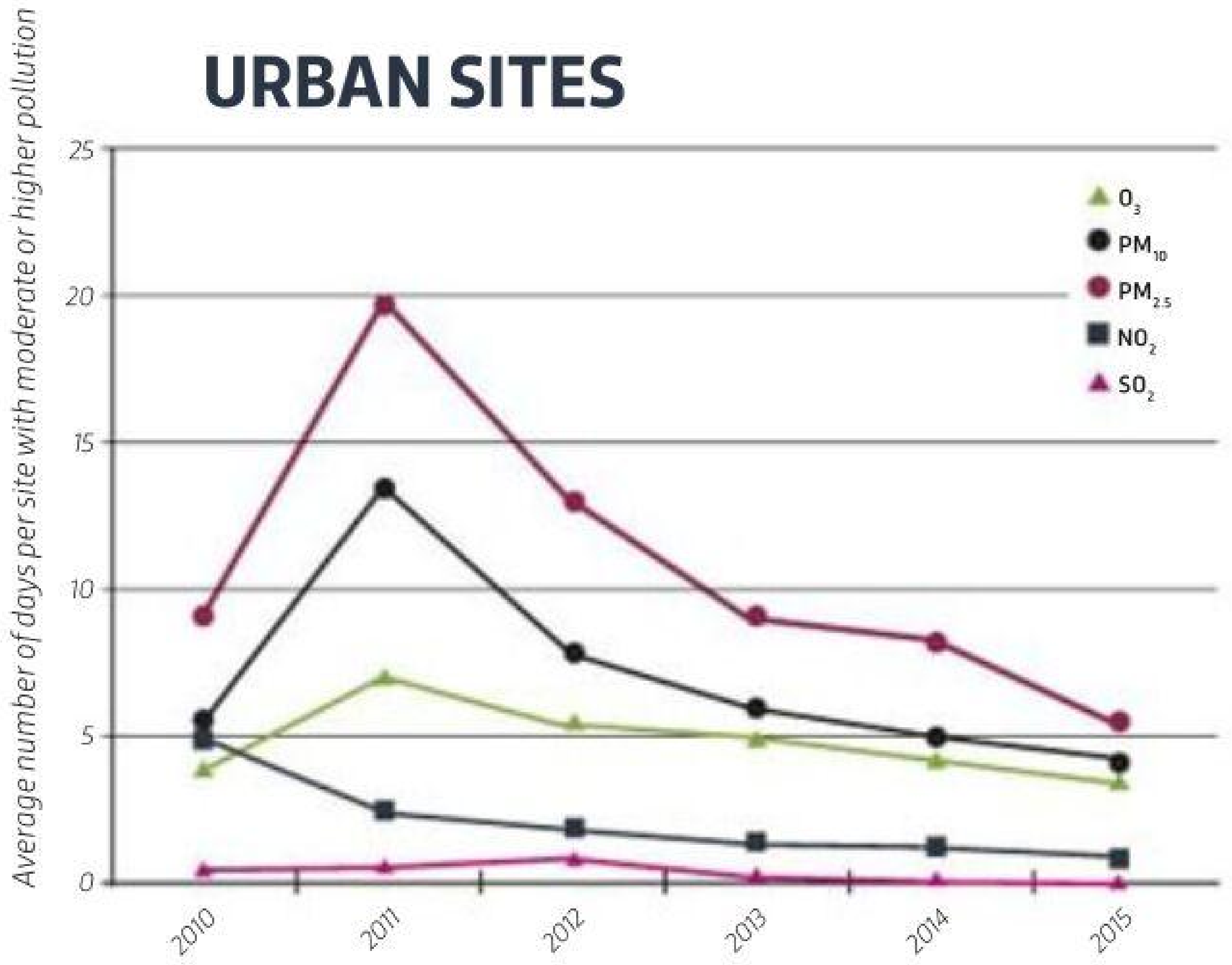
Over the course of five years, between 2010 and 2015, air pollution was monitored at rural and urban sites across the UK to generate this graph.

RURAL SITES



At rural sites, ozone (O_3) is the main cause of pollution on days with moderate or higher pollution levels. Sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) barely contribute to rural pollution.

URBAN SITES



At urban sites, particulate matter (PM_{10} and $PM_{2.5}$) were the main cause of pollution on days with moderate or higher pollution.

Air pollution is blamed for over 25 times more deaths than road crash fatalities

GETTY

supposedly cleaner ones. "But this was based on cars emitting NOx at the rates suggested by the manufacturers' test data," explains Lewis. Following EPA's revelations, the reason why there had been no decline was all too obvious.

NOx is not the only, or even most harmful, form of pollution emitted by diesel engines. They also spew out so-called particulate matter (PM), tiny specks of carbon laced with organic compounds like sulphates and metals. Short-term PM exposure causes irritation to the eyes, throat, nose and lungs, while people with conditions like asthma can suffer badly. But long-term exposure can pose a broader risk, says respiratory expert Prof Anthony Frew from the Royal Sussex County Hospital in Brighton: "There's data suggesting that diesel particles can leave people more prone to allergic responses, and promote inflammation of the airways."

Studies suggest that PM may pose a particular risk to the elderly and those with heart disease. "It can cause cardiac rhythm issues – though we don't know if the effect happens immediately on exposure, or takes some time," says Frew.

Mystery also surrounds the long-term effects of exposure. In a study of the health of over 360,000 people in England and Wales, a team led by Dr Anna Hansell of Imperial College London found that exposure to pollution in the 1970s still affected health almost 40 years later. The team also found that while levels of air pollution are now far lower than in the 1970s, it seems to be more toxic.

Exactly why isn't clear, and some experts have questioned the finding. Even so, there is an emerging consensus that air pollution is a major health hazard. In a report published just before the VW scandal broke, DEFRA put the estimated number of deaths in the UK due to oxides of nitrogen and PM at over 45,000 per year.

It's a shocking statistic – over 25 times the annual number of fatalities on roads. But it has been backed by the Royal College of Physicians and Royal College of Paediatrics and Child Health. Their joint report, published in 2016, stressed that the threat from air pollution has evolved over recent decades. "Everyone thought that the problem of air pollution was over. But how wrong we were," said Prof Stephen Holgate, chair of the group which put together the study. He believes the time has come for "urgent, determined and multidisciplinary action" to tackle the threat.

Exposure to air pollution in the 1970s still affected health 40 years later

CITY SHAKE-UP

Unsurprisingly, there are already calls for draconian action against vehicles in cities.

Earlier this year, smog was so bad in the Chinese city of Shanxi that officials restricted traffic by banning vehicles with number plates ending in odd numbers one day and even numbers the next. The same has been done before in other cities, such as Paris. And, last year, the French capital brought in anti-pollution stickers, which rank cars according to the emissions they produce, so that the authorities can easily ban less clean vehicles on days when pollution is high.

In 2016, London's mayor Sadiq Khan called for a scrappage scheme and taxes to encourage a switch to cleaner forms of transport. From 2020, London will impose charges on vehicles entering a new Ultra Low Emission Zone that fail to meet tight emission standards. Meanwhile, a network of displays giving air quality alerts is already being rolled out across London's bus routes, underground lines and major roads.

Other cities are going further, with diesel vehicles set to be banned from Paris, Madrid, Athens and Mexico City by 2025 under

HOW TO PROTECT YOURSELF FROM AIR POLLUTION

Many of us can't avoid the air from our city streets, but there are ways we can minimise its risk to our health

CHECK FORECASTS

Like the weather, UK air quality is forecast every day and the government's UK-Air website publishes maps rating air pollution on a scale of 1 (low) to 10 (high). According to health experts, most people can cope with routine exposure to even moderate levels of air pollution (up to 6), though anyone with respiratory conditions or heart problems might want to reduce strenuous activity if they feel unwell.

SLOW DOWN

But at levels 7 to 9, people with these conditions and the elderly are advised to cut back on such activity – as should anyone getting sore eyes, a cough or sore throat. At very high levels, the at-risk groups should avoid all strenuous activity, while everyone else should cut back on physical exertion, such as cycling.

PLAN YOUR ROUTE

Pollution levels vary from road to road, so planning your route can potentially lessen your exposure to airborne nasties. Londoners can head to the NHS's breathelondon.org and use the hourly updated air pollution map to make sure they sidestep the smog.

plans unveiled at a gathering of city leaders in December. But questions are already being asked about the effectiveness of such bans. A study of the impact of London's existing low-emission zone found that three years after it was set up, there was still no sign of improvement in either air quality or the respiratory health of children.

There is also concern that attempts to solve environmental problems will cause unintended consequences. Experts caution that banning vehicles from driving through city centres can simply shift the problem elsewhere – into residential zones. Meanwhile, NICE has made headlines by pointing out that even traffic control measures like speed bumps can affect air quality, with vehicles accelerating after crossing them, releasing a cloud of pollutants.

Other measures for tackling pollution have run into similar problems. Tree-planting has long been regarded as an ideal solution to air quality along roads. Research suggests that trees can mop up oxides of nitrogen, while a recent report by The Nature Conservancy claimed that trees can absorb as much as

The Smog-Free Tower in Beijing sucks in smog particles, creating a void of clean air around it

ALAMY, GETTY X3

Even traffic control measures like speed bumps can affect air quality

24 per cent of the particulate matter around them. But studies have also shown that trees give off their own pollution in the form of volatile organic compounds (VOCs). These can boost levels of ozone in the air and combine with other forms of pollution to affect vulnerable people, such as asthmatics. And some claim that some tree species can actually slow air currents that would otherwise shift pollution.

CLEAR SKIES

All sorts of other well-meaning ideas have been proposed for tackling urban air pollution – some more wacky than others. Artist Matt Hope has invented an air-purifying bike that uses a pedal-powered generator to work an air purification system, which feeds the rider fresh air through a hose.

Dutch designer Daan Roosegaarde came up with a similar solution, but on a larger scale. His 7m-tall air purifier, called the Smog-Free Tower, has been installed in four Chinese cities and one is currently under construction in Krakow, Poland. The device uses copper coils to create an electrostatic field that attracts smog particles, creating a void of clean air about a metre wide around the device.

From smog suckers to smog seeders, ‘cloud seeding’ has been used in the past to create artificial rain. At the 2008 Beijing Olympics, the technique was used in an attempt to deliver clear skies for the opening ceremony. It works by silver iodide particles being fired via rockets into clouds, where the particles act as points for liquid water to freeze around before falling to the ground. Reports now suggest that China plans to use cloud seeding to remove smog, as rain helps disperse air pollutants.

CLEANER CARS

But many believe the only effective answer is outlawing diesel cars in favour of cleaner tech, such as electric vehicles. Change is already afoot. In last year’s budget, the government announced customers buying new diesel cars will face a one-off tax increase this year. This has caused a 25 per cent fall in sales of new diesel cars.

But experts caution that this is no panacea. According to the Royal Colleges report, research has revealed a new source of road pollution: particles rich in toxic metals shed by brakes, tyres and road surfaces. “Even electric and alternatively fuelled vehicles can never be emission-free,” say the report’s authors.

And this is the problem – fixing one issue can reveal another. Ironically, it was environmental concerns that sparked the surge in popularity of diesel vehicles in the first place. As they use fuel more efficiently, diesel engines emit less carbon dioxide than their petrol counterparts.

The issue of air pollution may yet become a case study of the dangers of simple solutions to complex problems.

BBC WORLD SERVICE

Listen to *So I Can Breathe*, a season exploring air pollution bbc.in/2FpYF2p

Prof Robert Matthews is a science writer and visiting professor in science at Aston University.

To listen to an episode of *The Living World* about Ireland's peat bogs, visit ***bbc.in/1JF8xR3***

THE UNSUNG ECO-HEROES

Deserts, grasslands and wetlands play crucial roles in protecting the planet. If we ignore their destruction, it could spell global ecological disaster. But scientists are working to protect these precious terrains

WORDS: **JHENI OSMAN**

There are lots of invertebrates living in this grassy field, along with the cow

GRASSLANDS

While boreal forests – those found at high northern latitudes – are the largest carbon store on the planet, temperate grasslands are almost as important. The UK Countryside Survey estimates that 660 million tonnes of carbon are stashed away in our grassland soils – about one-third of all soil carbon stocks in the country.

"It's vital we protect grasslands for carbon storage," says Susan Ward, Senior Research Associate at Lancaster Environment Centre. "Conservation value is not just for the plants we see, it's also for insect pollinators and for the soil communities beneath our feet."

Free-range meat and milk come from the livestock herds that live off our grasslands. But many of our insect pollinators also live in this environment. Insects pollinate 80 per cent of all plant species in Europe, which is a service worth millions.

In the UK, over half our grasslands are 'agriculturally improved' to maximise yield. Species-rich grasslands, such as traditional hay meadows, have been decimated; less than three per cent of the original meadows are left.

After WWII agriculture boomed with an injection of fertilisers, which reduced plant diversity and increased atmospheric nitrogen. The knock-on effect of higher nitrogen levels is a rise in grassland growth, which reduces species richness and threatens biodiversity.

Reducing fertiliser use is one thing, but how else can we protect grasslands globally? According to plant ecologist Dr Joseph W Veldman, from Iowa State University, burning them may help. Fire is not a new phenomenon in grassy biomes – there's even evidence of fire adaptation in some plants. The key is to tailor the fire treatment to the land.

"Conservation agreements should recognise the important role that fire and large herbivores play in the maintenance of biodiversity in many grassy biomes," says Veldman. "I hope that old-growth savannahs and grasslands can achieve the kind of public conservation and restoration support that forests have had." ➔

GETTY

FACT FILE

34 per cent of terrestrial carbon is stored in grasslands all around the world.

60 per cent of newly forested areas in the EU were formerly permanent pasture or meadows.

40.5 per cent of the Earth's surface is covered by grasslands.

Calcareous (chalky) grasslands are Europe's most species-rich plant communities, with up to 80 plant species per m^2.

UNESCO defines grasslands as 'land covered with herbaceous plants with less than 10 per cent tree and shrub cover'.

Lewis, in Scotland's Outer Hebrides, has a long tradition of using peat for fuel

FACT FILE

50 per cent of wetlands have disappeared in the last century.

67 per cent of European wetlands that existed 100 years ago have been lost.

6 per cent of Earth's land area is wetlands.

Since the 1950s, 84 per cent of peat soils have been lost in the UK due to drainage and extraction.

A quarter of the most important wetlands in Europe are threatened by groundwater overexploitation.

WETLANDS

Formed over millions of years from moss, wood and dead plants, peat bogs can be vast – one the size of England was discovered in the Congo in 2014.

As decomposers can't survive in these wet, oxygen-poor conditions, organic matter doesn't get broken down, so the carbon that was in the plants gets trapped in the peat. Each square metre of peat can be packed with hundreds of kilograms of undecomposed organic matter. Research shows that about 450 billion tonnes of the element is sequestered in peat bogs around the world – that's the equivalent of 65 years' worth of our current carbon emissions from burning fossil fuels.

When peat bogs dry out, carbon is released into the atmosphere. Over the next few centuries, 40 per cent of carbon could be lost from shallow peat bogs and as much as 86 per cent from deep bogs.

Global warming won't just dry out peat bogs, it'll also cause frozen ones to thaw. Beneath the Arctic tundra lie more than 1,000 billion tonnes of carbon – double the human emissions since the Industrial Revolution. Human-made climate change has forced Arctic air temperatures to rise twice as fast as elsewhere around the planet, while permafrost temperatures have soared by 5.5°C since the 1980s.

While there have been fears that thawing permafrost could cause a sudden big 'belch' of methane and carbon dioxide to be released, recent research by the US Geological Survey found that it's more likely to be a gradual process. But the impact will be immense.

A so-called 'climate feedback loop' is what's really causing scientists to frown. If the permafrost warms up too much, some microbes will be able to decompose organic matter, releasing more greenhouse gases, warming the planet further and heating up the permafrost. Alarmed by a possible future of 'runaway global warming', some engineers are suggesting radical geoengineering solutions (see page 58).

The Kalahari Desert in Botswana is one of many deserts around the world that act as carbon sinks.

DESERTS

Deserts are huge carbon sinks. The Kalahari Desert in Botswana is full of drought-resistant cyanobacteria that fix atmospheric carbon dioxide. And recent research suggests that vast, hidden aquifers could be stashing carbon.

Researchers from the Chinese Academy of Sciences discovered a huge lake that holds 10 times more water than the North American Great Lakes beneath China's Tarim Basin, which is dominated by the vast Taklamakan Desert.

"Atmospheric carbon is being absorbed by crops, released into the soil and transported underground in groundwater," explains biogeochemist Yan Li from the Chinese Academy of Sciences. "These saline aquifers under the desert are covered by a thick layer of sand and [the carbon dioxide trapped in them] will never return to the atmosphere, probably becoming carbonate rocks or salt mines. It's basically a one-way trip. The nice side of this story is that this carbon sink is enhanced by human activities – irrigated farming speeds up carbon dioxide absorption."

Desert dust is also vital for many ecosystems. When dust is blown from the Sahara over the Iberian Peninsula, researchers have found that less radiation reaches Earth's surface than normal. Hence, desert dust cools the planet.

Saharan dust can be blown even further afield – across the Atlantic to the Caribbean, where it supports plants with nutrients when levels are low in the ocean. Meanwhile, dust from deserts in Mongolia and northern China is blown as far as the Pacific Ocean, where phytoplankton can feed on it.

"If there are changes in desert size or in the way people use land, there could be a greater source of dust getting to the Pacific," says Chris Hayes, from MIT's Department of Earth, Atmospheric and Planetary Sciences. "It's difficult to predict, but more dust getting to the ocean could help increase the growth of certain phytoplankton groups [that consume carbon dioxide]."

FACT FILE

11 per cent is the increase in desert foliage over the last two decades. This is due to soaring levels of carbon dioxide.

20 per cent of deserts are covered in sand.

One-third of Earth's surface is desert.*

Antarctica is the world's largest desert. The only plants that grow there are mosses and algae.

China is building a 4,500km-long 'Great Green Wall' made up of 100 billion trees to try to hold back the Gobi Desert.

Jheni Osman is a science journalist and presenter of *SciTech Voyager*. Her books include *100 Ideas That Changed The World* and *The World's Great Wonders*.

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*Based on the definition of a desert being a region with less rainfall in a year than it gives up through evaporation.

ALAMY X2

PROBLEM 3

EXTINCTION

Species have been dying out since time began. Those that can't adapt, don't survive. That's how evolution works. But the rate at which we're losing species is at an unprecedented high. We know each mammal, reptile, fish, bird and insect plays a key role in the specific ecosystem it inhabits – so the more we lose, the greater the peril to the planet and the species remaining on it. But what can we do to slow the losses down?

SOLUTIONS FOR

EXTINCTION – HOW TO BEAT MASS EXTINCTION P84
SPECIES SURVIVAL – 7 WAYS SPECIES EVOLVED TO SURVIVE P92
CORAL DEPLETION – THE CORAL MATCHMAKER P94
CONSERVATION – SHOULD WE LET PANDAS GO EXTINCT? P98

GETTY

HOW TO BEAT MASS EXTINCTION

All the signs in nature suggest another mass extinction is imminent – and this time humans, rather than a meteorite, are to blame. But we're working on ways to save the species facing peril

WORDS: **DUNCAN GEERE**

ILLUSTRATION: ANDY POTTS

All around the world, humans are hacking branches off the tree of life. Since the last ice age – which ended about 10,000 years ago – the extinction rates of species of plants, mammals, birds, insects, amphibians and reptiles have skyrocketed, with one estimate putting the current rate of loss at up to 140,000 species per year. That's a problem – not just for the species that are dying out but for humans, too. We depend on our companions for food security, clean water, clothing, and even the air we breathe.

In 2009, the Stockholm Resilience Centre listed biodiversity loss as one of nine 'planetary boundaries' that cannot be crossed without the world suffering irreversible environmental change (other boundaries include ozone depletion, climate change, and ocean acidification). Without Earth's biodiversity, humans wouldn't be here at all. And even the most conservative estimates of species loss show cause for alarm.

The latest calculations come from a group of biologists led by Stanford University's Paul Ehrlich and Gerardo Ceballos from the National Autonomous University of Mexico, who have published results showing that Earth is

SVALBARD GLOBAL SEED VAULT

The roof and front of the Svalbard Global Seed Vault are adorned with stainless steel prisms and mirrors. As light reflects off them, they emit a ghostly glow that changes throughout the days and seasons. Artist Dyveke Sanne was commissioned to come up with this striking design, thanks to a legal requirement that says all Norwegian public and civil buildings exceeding a certain build cost must incorporate an artwork element.

experiencing the beginnings of an extinction event at least as large as the one that killed the dinosaurs, and perhaps as big as the other five major extinctions in our planet's history.

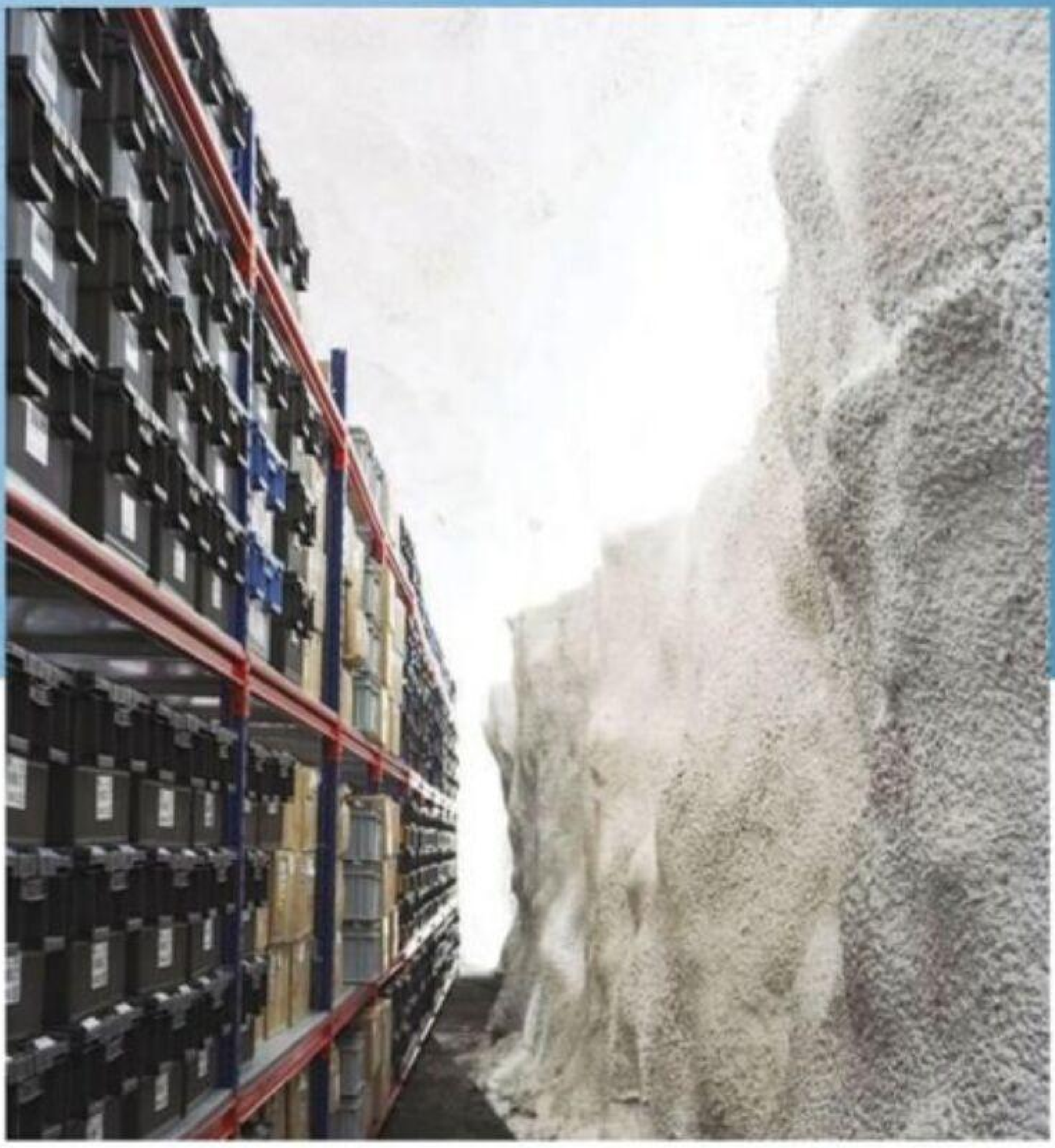
"We're not there yet, but we can easily get there in a century," says Ehrlich.

Their paper sets out a best-case scenario – one that only counts species as going extinct if we've seen them go extinct, and where the 'normal' extinction rate for Earth before humans came along is about twice as high as previous estimates. What did their findings say, with these assumptions in place? "You still get tens to hundreds of times more rapid extinctions today than during the times when there weren't mass extinction events," explains Ehrlich. "In other words, a very clear sign that we're entering a sixth mass extinction event."

Ehrlich, it should be pointed out, has a history of making dire warnings about humankind's impact on the planet, with varying degrees of accuracy. In his 1968 book *The Population Bomb*, he brought several decades of academic concern about Earth's rising population to the mainstream, predicting mass famine, disease and social unrest on a global scale. A few years later, he predicted that by the year 2000 the United Kingdom would merely be "a small group of impoverished islands". Thanks to the Green Revolution, his predictions largely failed to come to pass. Ehrlich has since admitted that society has been more resilient than he expected.

> "It's a very clear sign that we're entering a sixth mass extinction event"
>
> ***Dr Paul Ehrlich, Stanford University***

Knowing this, you'd be forgiven for taking Ehrlich's predictions of species extinction with a pinch of salt – but he's not the only academic alarmed at the rate of biodiversity loss. In 2011, biologists led by Anthony Barnosky (a co-author on Ehrlich's recent paper) described ongoing mass extinctions in a paper published in the journal *Nature*, writing that "current extinction



ABOVE: Svalbard houses frozen seed samples from all over the world

rates are higher than would be expected from the fossil record". Then, in 2015, a group led by Tim Newbold from the United Nations Environment Programme reported that humans are directly responsible for a 13 per cent reduction in the number of species. Ehrlich says that his results are "a conservative confirmation of something that basically every scientist knows".

STOCKPILING NATURE

Around the same time that Ehrlich was making his dire predictions about the future of the human race, an environmental movement was blossoming around the globe. The first Earth Day was celebrated in 1970, and Greenpeace was founded in 1971. All over the world, various scattered, underfunded conservation schemes began to join up into a wider network dedicated to preserving the world's animals and plants.

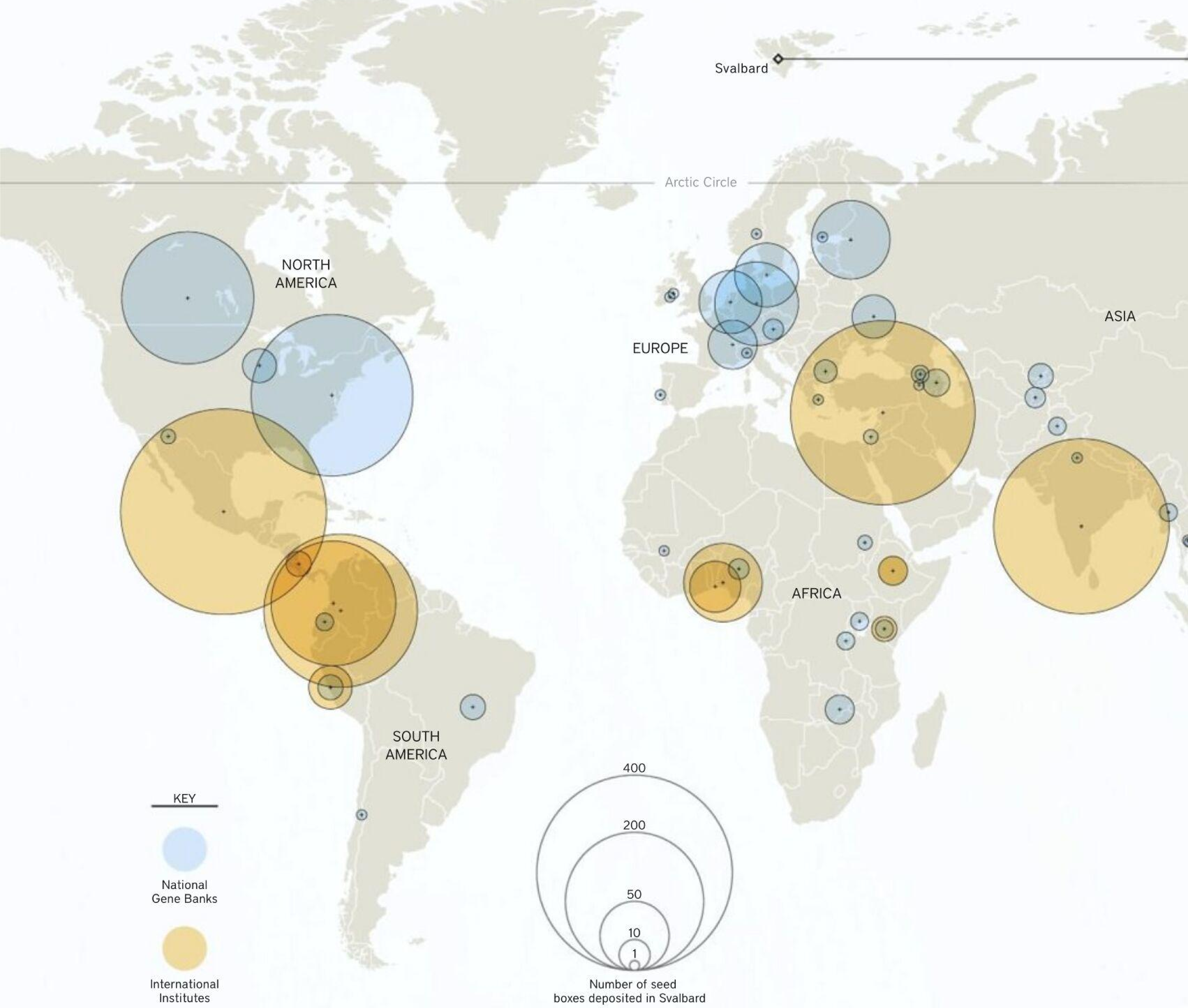
In 1992, 168 countries signed the United Nations' Convention on Biological Diversity, in recognition that conservation of biological diversity is "a common concern of humankind". That convention underpins many of the laws that protect biodiversity around the world today – it is seen as a vital document for conservation and sustainable development. One major ➜

BELOW: Svalbard's seeds are carefully stored in a controlled environment

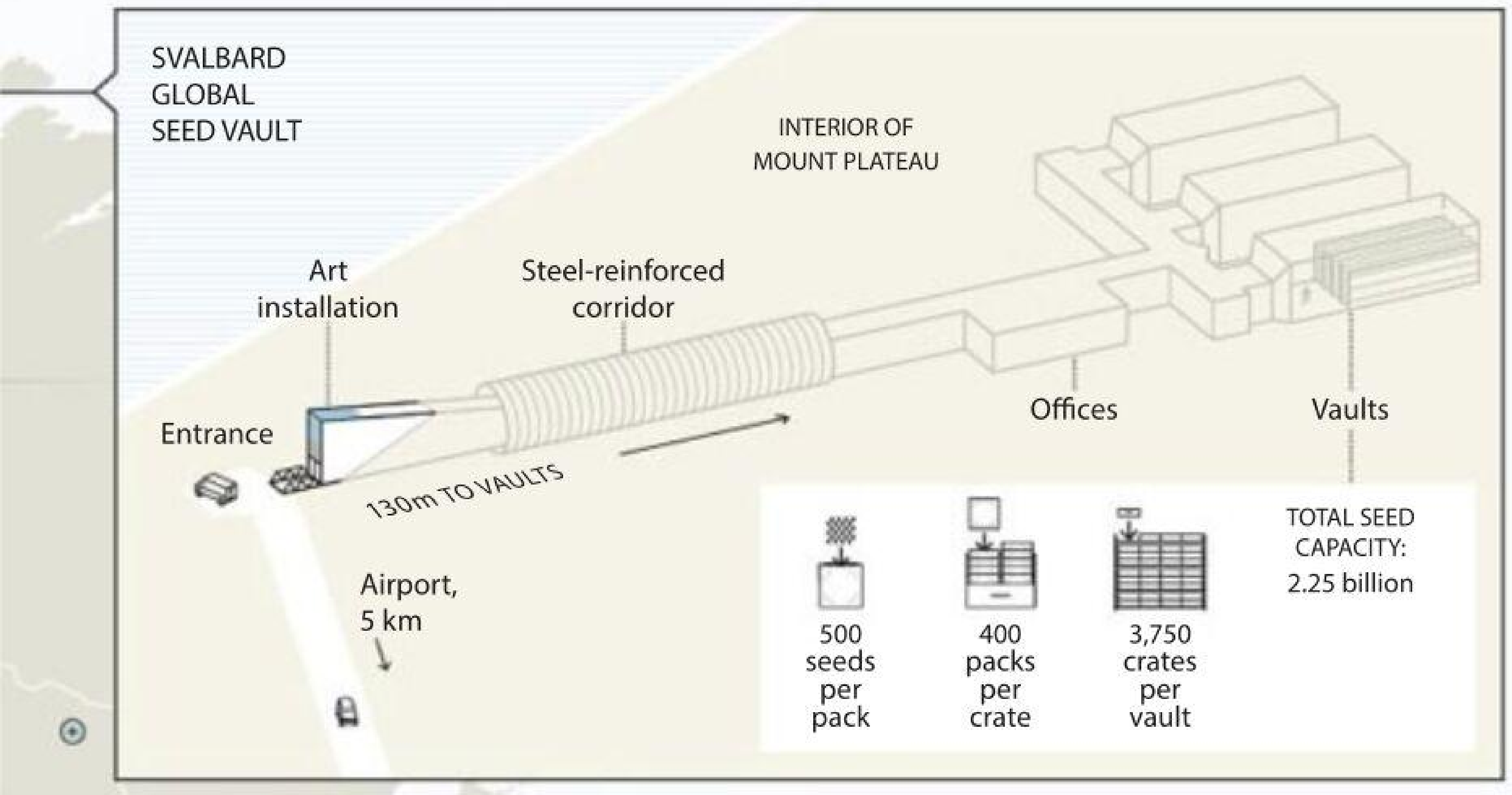
ERWIN ZWART/THE OCEAN CLEANUP, KOSUKE ARAKI, ALAMY

THE GLOBAL SEED BANK NETWORK

Small gene banks and international institutes from around the world all deposit seeds into Svalbard

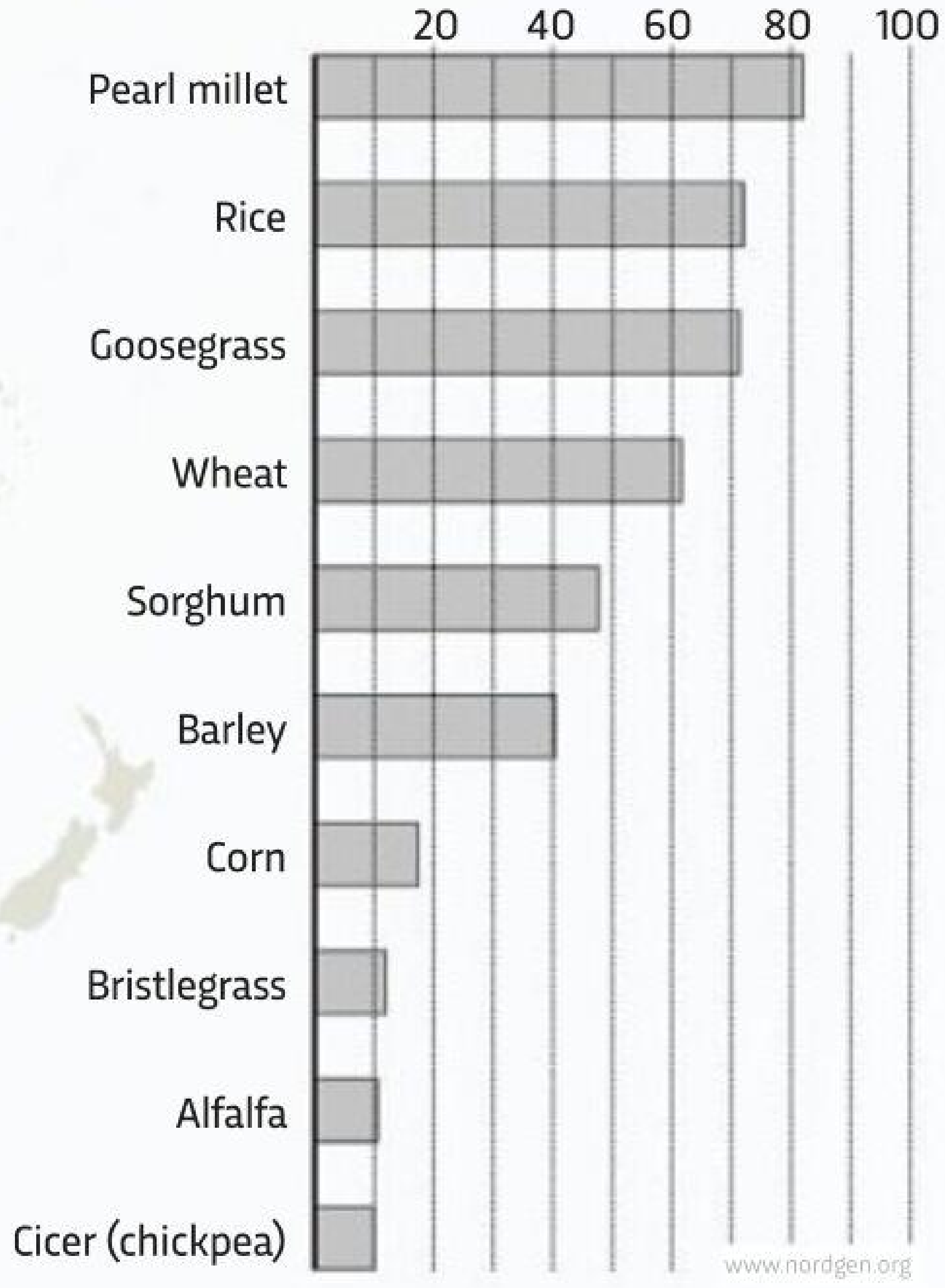

Svalbard
Arctic Circle
NORTH AMERICA
EUROPE
ASIA
AFRICA
SOUTH AMERICA
KEY
National Gene Banks
International Institutes
400
200
50
10
1
Number of seed boxes deposited in Svalbard

> **“It’s important to have this diversity for the future. Without it, the building blocks of agriculture don’t exist”**
>
> ***Brian Lainoff, Crop Trust***



*As of August 31, 2015

LARGEST SEED STOCKS IN STORAGE IN SVALBARD
(in millions)



www.nordgen.org

ILLUSTRATION: HAISAM HUSSEIN

project under its auspices, for example, is the Global Strategy for Plant Conservation, which includes 16 ambitious targets for understanding and conserving plant diversity.

Another example is a treaty that came into force in 2004 with the objective of guaranteeing food security through conservation and sustainable use of the world’s plants. It called for the creation of a Global Crop Diversity Trust, which could ensure the availability of plant diversity essential for food and agriculture. This organisation, based in Germany and known more commonly as the Crop Trust, funds a global network of gene banks, where seeds and other genetic material can be preserved for decades, even for many centuries.

“We work around the world with collections of crop diversity, to conserve them and make them available to farmers, breeders and scientists forever,” explains Brian Lainoff from the Crop Trust. “It’s important to have this diversity for the future, so that scientists and breeders can grow crops that will be able to face higher temperatures, less water, new diseases and new pests. Without the diversity, the building blocks of agriculture don’t exist.”

FORT KNOX FOR NATURE

The Crop Trust works with national gene banks representing whole countries, as well as those focused on a particular crop, such as the International Rice Research Institute in the Philippines. But it also has one of its own – the Svalbard Global Seed Vault, dug into the side of a mountain on a frigid island just 1300km from the North Pole, where the Sun doesn’t rise for more than four months during winter. “The Svalbard Seed Vault is a backup for the world’s gene banks,” says Roland von Bothmer from the Nordic Gene Resource Center, which helps operate the facility.

There are seeds sitting on the shelves of Svalbard’s vault from 5,103 species and 232 countries – including several, such as Yugoslavia, that no longer exist. Svalbard was chosen because it’s geologically stable, and because the frozen ground means that cooling the seeds to the necessary temperature for storage is easier. The remote location reduces the chances of sabotage and the entrance is 130m above sea level, meaning that it'll be safe from rising oceans even if both of Earth's ice caps melt.

The global gene banks split samples between three locations: their 'home' bank, a second bank in another country, and also in Svalbard where only the depositing organisation can access them. As such, withdrawals are rare.

But while the vault has been built into the frozen rock of Svalbard and is designed to last for centuries, if not millennia, its financial situation is considerably more precarious – especially because some are sceptical about how worthwhile the project really is, arguing that the money it costs to maintain the seed bank would be better spent on preserving crops in their natural habitats. Operational costs are shared between the Norwegian government, which for political reasons can't guarantee funding beyond the duration of a parliament, and the Crop Trust, which relies on donations from charitable foundations and other governments around the world.

NOAH'S ARK 2

It's not only plant seeds that are stored in gene banks – animal biodiversity is being cryopreserved in much the same way in almost a dozen 'frozen zoos' worldwide. One of the first was at the San Diego Zoo, where 8,400 samples from more than 800 species have been kept in liquid nitrogen since 1976. Stored material can be kept indefinitely and used for artificial insemination, in vitro fertilisation, or cloning of animals in the future.

The US Fish & Wildlife Service has been using 20-year-old ferret sperm to improve genetic diversity in a struggling population of black-footed ferrets. Once abundant on the Great Plains, by the early 1980s *Mustela nigripes* had been hunted to near-extinction. In a bid to save the species, the last 24 ferrets were rounded up and taken into captivity; six died, but captive breeding from the remaining 18 has enabled the population to grow back into the hundreds. But having such a small gene pool meant the population was becoming increasingly inbred. So, in 2008, the scientists reached for the frozen sperm samples stashed away two decades previously. Measures of inbreeding

IF THESE DIE OUT, WE WILL TOO

BEES

Insects have been pollinating flowers for 100 million years and about 70 per cent of our agriculture today depends on them continuing to do so. But pesticides, habitat loss, invasive species and diseases are driving global bee populations into a severe decline, with potentially catastrophic consequences for food production.

BATS

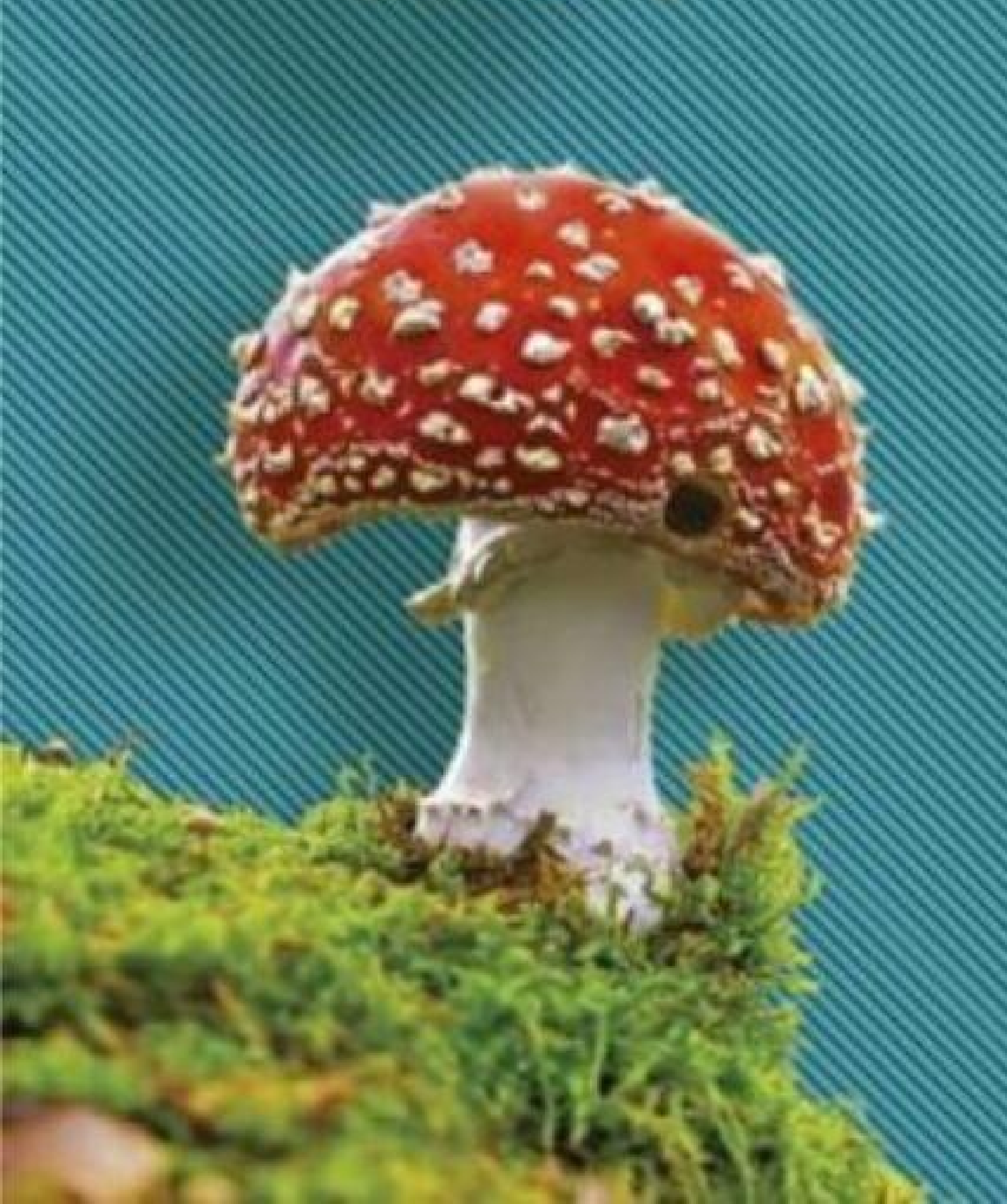
These mammals play a vital role in food production, particularly in the tropics. They pollinate flowers and disperse fruit seeds, but also consume insect pests – saving us millions of dollars in pesticides. Without bats, we'd have no bananas, mangoes or tequila.

CORAL

Earth's richest ecosystems are coral reefs. They offer a home to untold amounts of biological wealth – fish, molluscs, sharks, turtles, sponges, crustaceans and many more. They protect coastlines from storms, filter water and store carbon. Not bad for 1 per cent of the Earth's surface.

PLANKTON

Do you like breathing? You've got plankton to thank – it produces between 50 and 85 per cent of the oxygen in the atmosphere. These tiny organisms also sink carbon to the bottom of the oceans. Not only that, they're the base of the world's food webs as they are eaten by everything else.



FUNGI

Fungi are nature's recyclers, turning waste into vital nutrients for numerous plants and animals. As well as this, they help produce various cheeses, chocolate, soft drinks and many vital drugs, including antibiotics such as penicillin and cholesterol-controlling statins.

ZOO
GENETICS TANK VIII
18HC

San Diego Zoo contains over 8,000 individual samples from 800 different animal species

GETTY X5, ALAMY

have since decreased by 5.8 per cent.

But animal biodiversity is mostly preserved alive, in the world's nature reserves. There are tens of thousands around the world, and their protected status allows them to maintain ecological processes that have struggled to survive against the onslaught of human development. Several case studies have shown positive effects of these protected areas on plant and animal species, but many ecologists say they're not enough to combat biodiversity loss on the scale we're seeing.

The University of the West of England's Dr. Mark Steer is one of them. "While nature reserves play a hugely important role in enabling some of our rarer species to cling on in largely hostile environments, our current system of protected areas is wholly inadequate if we want to maintain and enhance biodiversity," he explains. "If we cannot embed wildlife-friendly habitats throughout the wider landscape, creating extensive and resilient ecological networks, then we will continue to see wildlife ebbing from our lives."

Some countries are, though, starting to build such embedded habitats. Wildlife corridors allow plants and animals to migrate between green spaces, joining up isolated populations, and allowing them to find the resources they need to survive. One ambitious project is the European Green Belt, which has turned the border that once formed the Iron Curtain into a green corridor that runs from the northernmost point of Europe down through more than 20 different countries until it reaches the Mediterranean Sea.

So far, though, what we've accomplished is nowhere near sufficient to slow the pace of mass extinction. More national parks, wildlife corridors and seed banks need to be created, otherwise whole species will continue to die out faster than we save them.

But, on the 10th anniversary of the opening of the Svalbard Seed Vault, proponents would say it has performed an invaluable role. With more than a million seeds now safely deposited in the vault, it is estimated that it now houses around 40 per cent of the world's total agricultural seed diversity. As part of the anniversary celebrations back in February, more than 60,000 new seed samples from about 20 gene banks were added to the vault. Projects like this give us hope for the future. And, just maybe, we can slow the rate of extinction, and one day stop it altogether.

Duncan Geere is a science writer based in Sweden.

BBC RADIO 4

Listen to *Extinct!* which discusses how we are living through a sixth mass extinction event
bbc.in/2oRGBV6

7 WAYS SPECIES EVOLVED TO SURVIVE

Human interference has forced many creatures to evolve rapidly or risk dying out. But in some cases, this has been to the detriment of other species

WORDS: **JULES HOWARD**

1 WHITTLED WINGS

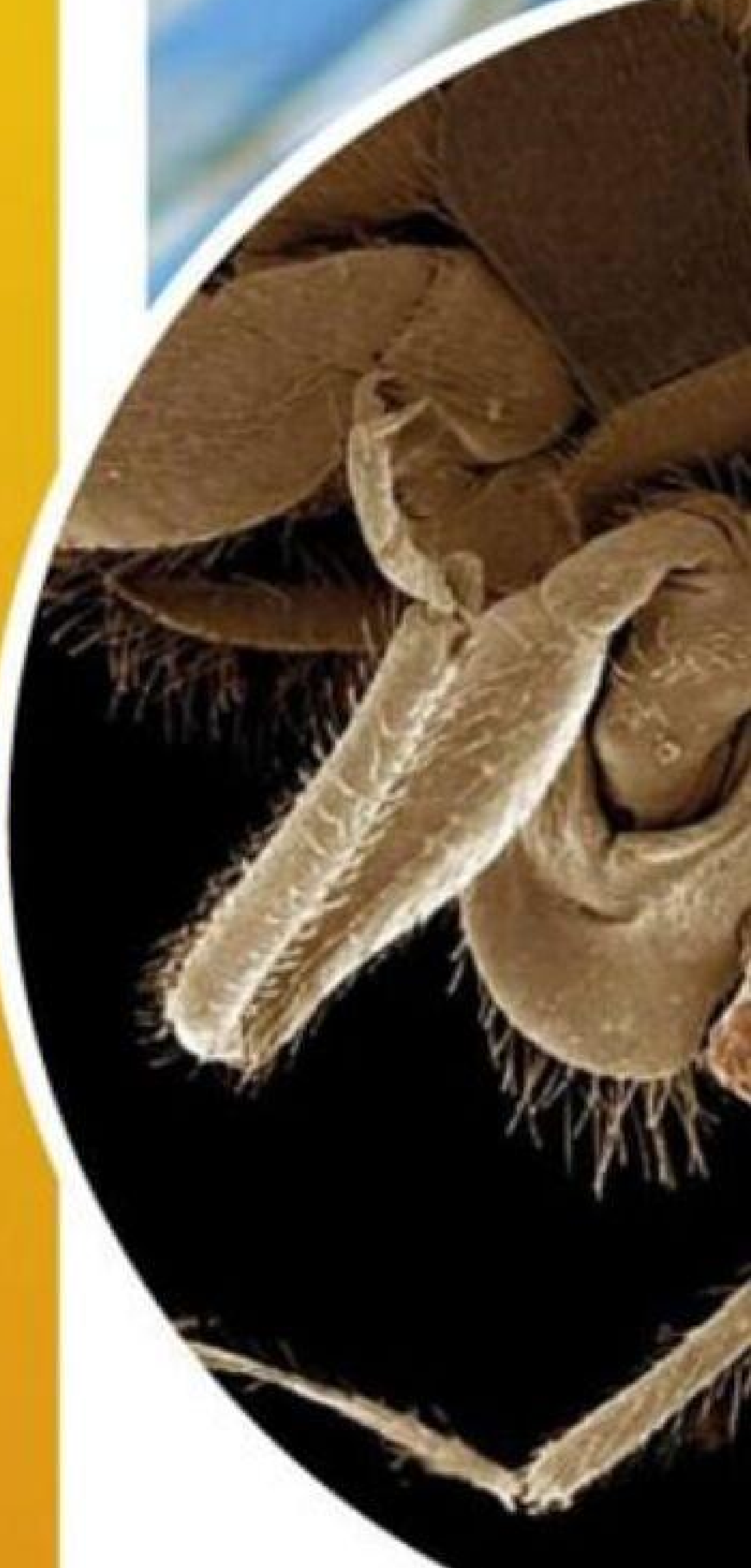
As traffic on many of the world's roads increases, some birds, such as cliff swallows, are already adapting. In a 2012 study incorporating three decades of data, the average wing length of cliff swallows nesting upon motorway overpasses was observed to have reduced by 5mm. The reason? Short wings accidentally endow birds with a more dynamic flying style, meaning they can dodge vehicles better than longer-winged counterparts. These small-winged variants have since flourished and, incredibly, observations of cliff swallow roadkills are down to a quarter of what they once were.

2 EARLY RISERS

Researchers studying pink salmon in Alaska have found that, as waters have warmed over recent decades, fish with the gene for earlier migration from the ocean have become more numerous, because they reach streams to spawn before the waters become too warm. The changes seem to take place over just one or two generations, meaning that – so far – these salmon have been able to keep one step ahead of climate change.

3 ISLAND LOVERS

When Darwin visited the Galápagos, he realised that remote islands are hotbeds of evolution, seeded by stowaways that reach their shores and adapt to local conditions. In 1971, scientists simulated this by moving five pairs of Italian wall lizards to an uninhabited Croatian island. Revisiting the island 30 years later, they found that the lizards, originally insect-eaters, had evolved a primitive form of herbivory. Their gut had changed to include fermenting chambers, and their jaws had become stronger.

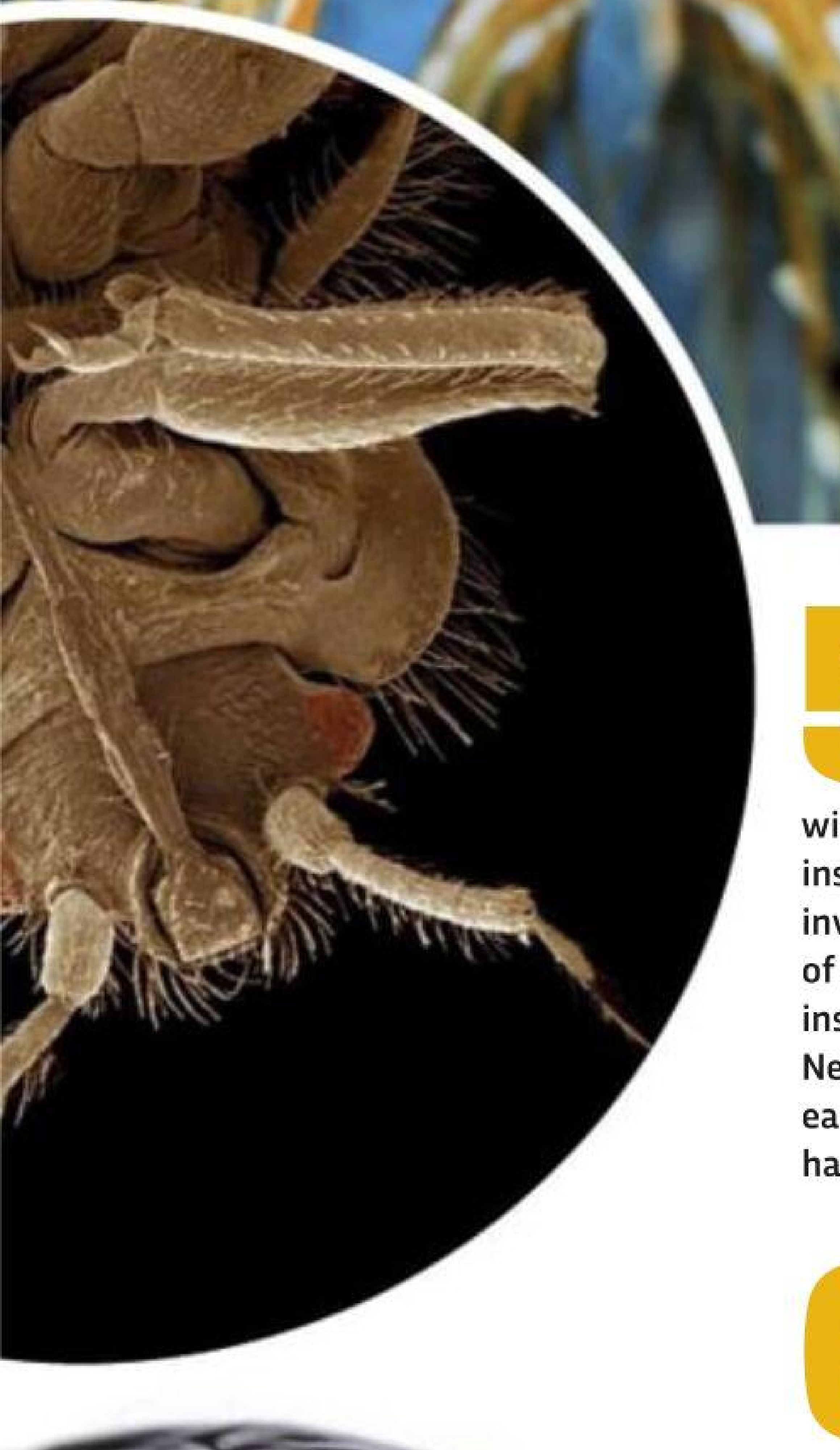


ALAMY X4, GETTY X3, NATUREPL.COM

4

LION’S DEN

A lionfish can consume 20 fish in half an hour and eat prey measuring two-thirds of its body length, and a female can release 30,000 eggs every four days. With stats like these, it’s no wonder they have become pests, spreading rapidly across the Caribbean and up the east coast of the US. Experts blame the pet trade. The spread most likely began when captive fish – perhaps as few as 12 individuals – were released from aquariums in Florida, which then began to proliferate. Conservationists are now trying to encourage people – and even sharks – to eat them.



5

BADASS BUGS

No matter how many antibiotics or insecticides we throw at Nature, it always smiles fondly upon genes that are endowed with resistance to these substances. That’s how insecticides like DDT, once commonly sprayed upon invertebrates the world over, have led to the evolution of tougher bedbugs. Bedbug resistance to two common insecticides comes courtesy of just a single mutation. Nearly all bedbugs alive today are the descendants of earlier mutants who carried the resistant gene, and have hence become extremely difficult to eliminate.

6

MINI MOUTHS

In 1935, Australian scientists came up with a new crop pest control method – introducing cane toads from the Americas. The toads soon roamed away from their original site. Loaded with deadly poison makes them lethal to many predators. Yet the toads have had a surprising effect on the green tree snake and the red-bellied black snake. Over generations, their jaws have shrunk, since smaller jaws eat smaller toads and ingest less poison.

7

SHRINKING TEETH

Modern creatures are survivors, chiselled through natural selection. But humans also have the potential to control which animals live and die, leading to what is called artificial selection. The effect of a century of poachers killing elephants with the largest tusks is already having an impact, with more elephants either being born with the genes for smaller tusks or no tusks at all. In Mozambique’s Gorongosa National Park, for example, more than 33 per cent of all females are tuskless. Back in 1930, just 1 per cent of Africa’s elephants were tuskless.

THE CORAL MATCHMAKER

We're in the midst of a ***mass extinction*** *event.* ***Jamie Craggs*** *hopes his research could save coral reefs from this fate*

It's not a good time to be a wild animal or plant. Extinction rates are soaring. Every day, up to 100 species are lost forever, and it's estimated that around 25,000 species are teetering on the edge of oblivion. In the oceans, it's thought that 60 per cent of the world's coral reefs could die over the next 20 years.

It's not all bad news, however. Species can, and have, been rescued from the brink of extinction, and sometimes their saviours can be found in the most unexpected places, such as the bowels of a south London museum. Jamie Craggs, the aquarium curator at the Horniman Museum and Gardens, is brimming with excitement because, very soon, the mini coral reefs he has created will explode with potential new life. It's the result of five years' hard graft, working out the exact conditions needed to make captive coral spawn.

In the wild, corals like the ones Craggs is working on reproduce once a year, all on the same night and at the same time. The process, called synchronous spawning, sees coral colonies release clouds of sperm and eggs into the water, where they are mingled and dispersed by the currents. It's an evolutionary adaptation that enables the sex cells of distant coral colonies to meet and mix, minimising the risk of inbreeding.

Inside coral cells are algae-like organisms called symbiotic zooxanthellae, which give them energy and colour. But rising sea temperatures are causing the zooxanthellae to desert the corals, leaving them bleached and susceptible to disease. The survivors find themselves so isolated that successful sexual reproduction becomes difficult.

As part of his PhD at the University of Derby, Craggs has devised a closed-tank system that mimics the natural environment of corals. By controlling the type and duration of light, along with nutrient levels, water chemistry and temperature, he can reliably and predictably induce coral spawning to within half an hour. "It's a game changer," he says. "No one else has ever been able to do that before."

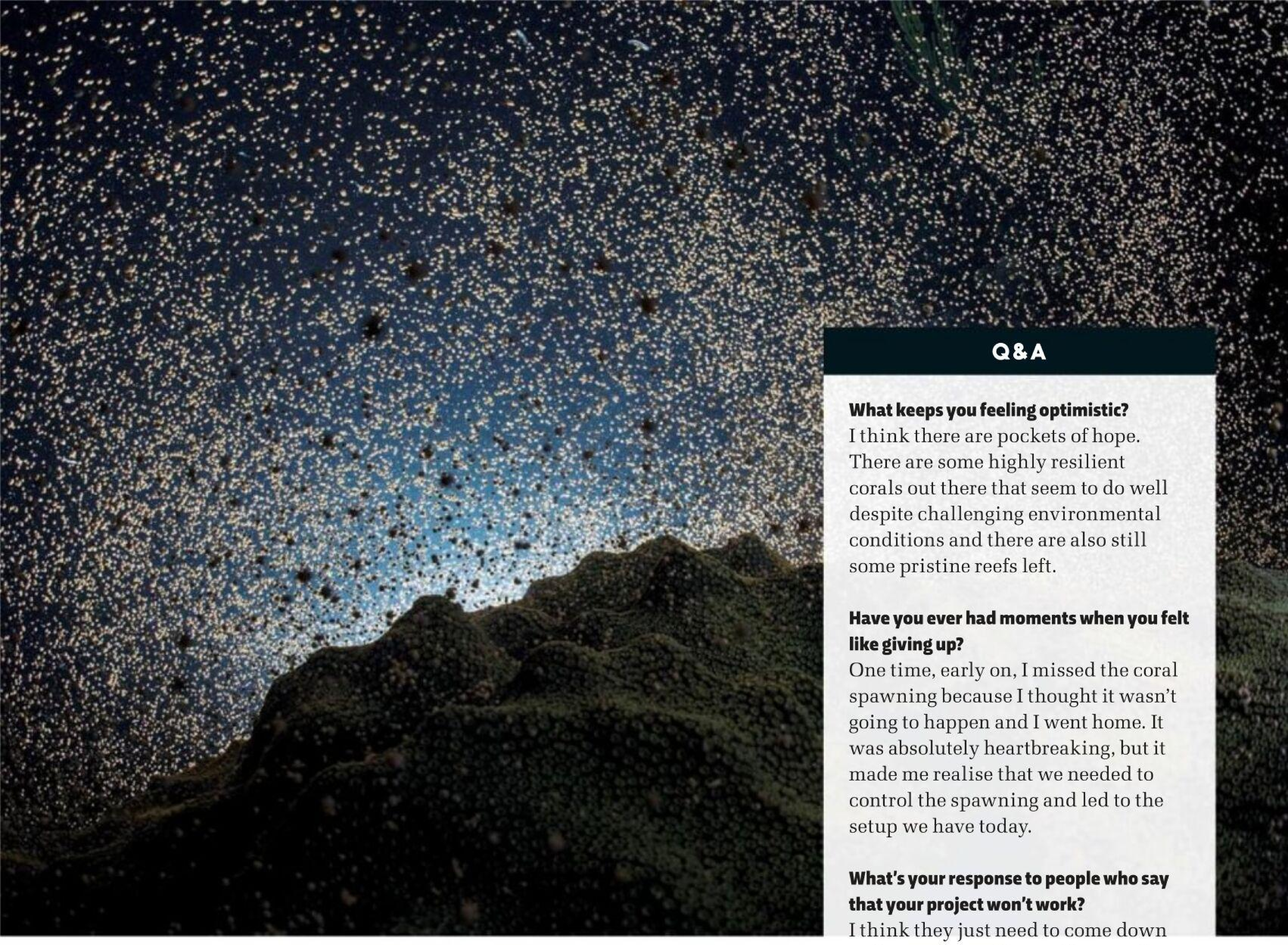
At 1pm, when the spectacle begins, thousands of tiny pink spheres, each no larger than a sugar granule, are released by the coral and float to the surface of their darkened tanks. These particular corals are hermaphrodites, so each package contains both eggs and sperm. In a UK first, Craggs and his colleagues have used them for in vitro fertilisation. "The potential is huge," Craggs says. "We can now make the coral in our collection spawn four or five times a year." The only limiting factors are the number of tanks and the amount of time that Craggs and his team have.

> **"At 1pm, when the spectacle begins, thousands of tiny pink spheres, each no larger than a sugar granule, are released by the coral and float to the surface of their darkened tanks"**

As the young corals grow and form new colonies, they provide an expanding resource for scientific study. In the wild, some corals are naturally more resistant to rising temperatures, disease and pollution. Craggs has the perfect setup to identify the features that endow these species with their resilience and he hopes breeding them together might boost levels of genetic diversity to produce robust corals that are more likely to survive.

And if his plan proves to be successful, who knows? There's no reason why the same techniques can't be applied to real ailing reefs in the oceans, giving the world's coral and the myriad creatures that depend on it the chance of a brighter, more colourful future.

SOPHIA SPRING ILLUSTRATION: MARIO WAGNER



Q&A

What keeps you feeling optimistic?
I think there are pockets of hope. There are some highly resilient corals out there that seem to do well despite challenging environmental conditions and there are also still some pristine reefs left.

Have you ever had moments when you felt like giving up?
One time, early on, I missed the coral spawning because I thought it wasn't going to happen and I went home. It was absolutely heartbreaking, but it made me realise that we needed to control the spawning and led to the setup we have today.

What's your response to people who say that your project won't work?
I think they just need to come down and spend some time with us so they can see what we've achieved. What we're developing here is going to underpin and support lots of other great, positive work.

If you were able to rent out a billboard in Times Square, what would you write on it?
A picture tells a thousand words, so I'd put up photos of coral reefs: the colourful, healthy, vibrant ones full of fish and then the bleached, damaged, empty, dying ones… before and after shots.

What will your field of research look like in the year 2050?
In much the same way that people grow trees in nurseries today, I think we'll find coral being grown in land-based nurseries on a large scale and then used to restock the reefs.

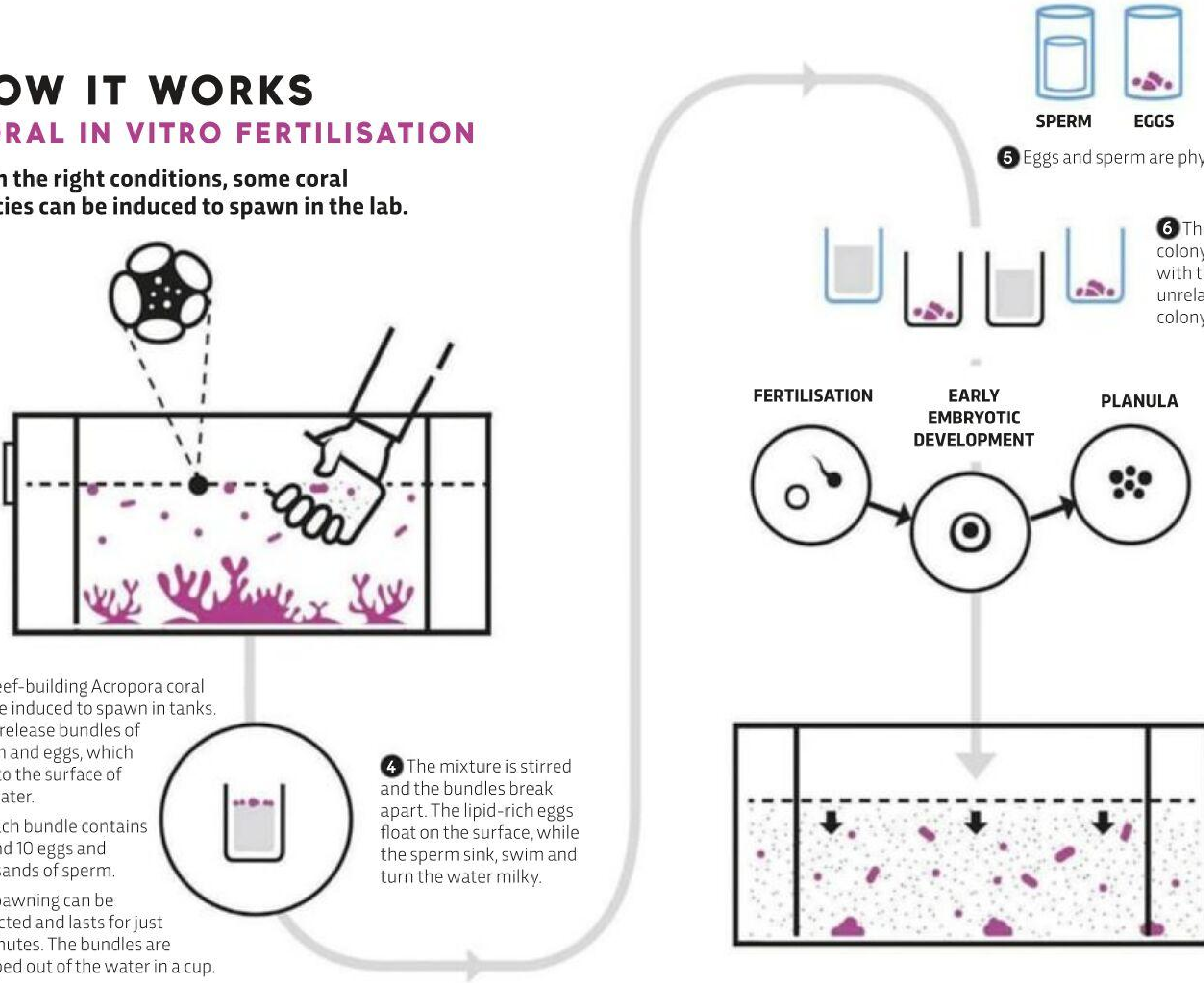
ABOVE: Resembling a starry night sky, spawn from a colony of coral is released in the Cayman Islands

LEFT: These corals in North Sulawesi, Indonesia, have bleached in response to a rise in sea temperature

HOW IT WORKS

CORAL IN VITRO FERTILISATION

With the right conditions, some coral species can be induced to spawn in the lab.



❶ Reef-building Acropora coral can be induced to spawn in tanks. They release bundles of sperm and eggs, which float to the surface of the water.

❷ Each bundle contains around 10 eggs and thousands of sperm.

❸ Spawning can be predicted and lasts for just 15 minutes. The bundles are scooped out of the water in a cup.

❹ The mixture is stirred and the bundles break apart. The lipid-rich eggs float on the surface, while the sperm sink, swim and turn the water milky.

❺ Eggs and sperm are physically separated.

❻ The sex cells from one colony (black cups) are mixed with those from an unrelated, genetically distinct colony (blue cups).

❼ Once the eggs are fertilised, the cells will start dividing to create an embryo. Each embryo will eventually become a larva called a planula.

❽ Planulae are transferred into a settlement tank. They sink and attach to specially prepared tiles where they begin to grow into coral polyps with mouths and tentacles. A few weeks later, zooxanthellae are added to the tank, which the corals incorporate into their cells.

SAVE OUR SPECIES

THE FROZEN ZOO

At San Diego Zoo Institute for Conservation Research, scientists have created a ‘frozen zoo’ of cells and embryos from endangered and extinct species. As the largest, most diverse collection of its kind, the initiative seeks to preserve the world’s biodiversity in cellular form. Attempts to rescue the northern white rhino (there are just three left) focus on samples stored at the zoo.

GENETIC MODIFICATION

The endangered black-footed ferret could become the first wild animal to have its DNA deliberately altered. The species suffers from inbreeding and sylvatic plague. Revive & Restore, a US organisation pioneering the use of genetics in conservation, wants to edit its genome to make it disease-resistant, and clone ferrets from the cells of dead individuals to restore genetic diversity.

GENOME LIBRARIES

The kākāpō is a flightless parrot endemic to New Zealand. Decimated by invasive species, the 151 birds alive today are the focus of a conservation programme. They live on predator-free islands, where their breeding is managed. Some birds are artificially inseminated, and chicks can be fostered by skilled kākāpō mothers. The genome of every living kākāpō is being decoded to guide future conservation.

ALAMY X2, GETTY X3 ILLUSTRATION: ACUTE GRAPHICS

SHOULD WE LET PANDAS GO EXTINCT?

Pandas are conservation mascots. But do they have the right to hog funding – or should we invest less cash in them and more in other species?

WORDS: **JULES HOWARD**

Panda conservation is big business. Wild panda conservation is aided in part by the rental costs of captive pandas, which are housed in zoos around the world at a cost of hundreds of thousands of pounds each year – Edinburgh Zoo pays £600,000 annually for the privilege of housing two pandas.

Is all of that money being well spent? That depends. In 2016, a two-year-old panda bred in captivity became the sixth to be released back into the wild – after 50 years of effort. But wild panda numbers do appear to be rising. In 2003, there were only 1,600 wild pandas. Now there are nearer 1,850 – an increase of 16 per cent. Giant pandas are no longer considered officially endangered, merely 'vulnerable', thanks to a decrease in poaching and an expansion in protected habitat.

But could the £20m spent on pandas be better spent elsewhere? There are numerous far more threatened species. The Nubian flapshell turtle is a funky-looking reptile whose numbers have fallen by 80 per cent in just two generations. Couldn't it do with some cold hard cash too?

A 2012 analysis showed that, of the 1,200 mammals threatened with extinction, just 80 species were used by organisations to raise funds. The reality is that we buy into cute – and pandas benefit from having a body that's shaped like a teddy bear. The Nubian flapshell turtle just cannot compete.

For this reason, pandas and certain others are given special value as 'umbrella species'. Protect them and you protect others within their shared habitats. Umbrella species do have their uses, but lesser species are bound to get wet in the face of relentless, driving rain made worse by human interference. Ultimately, only the creatures holding the umbrella may stay dry.

Pandas have been overused as a conservation character. But perhaps as we attain a deeper understanding of how conservation really works, these much-loved bears can encourage us to look after our ecosystems better.

Jules Howard is a zoologist, presenter and author.

GETTY

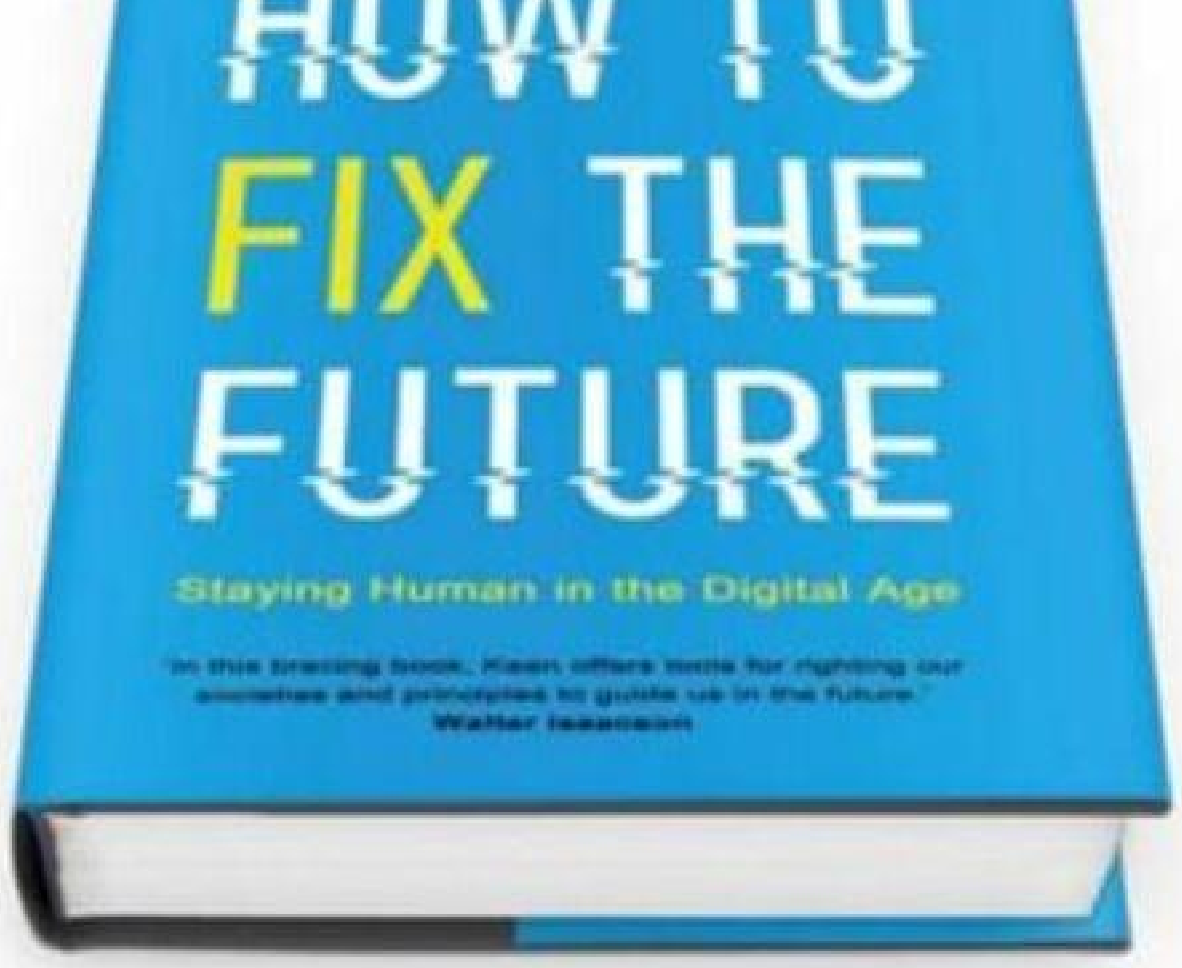
THE FUTURE IS
BROKEN...

SO HOW CAN WE FIX IT?

A provocative look at how we can protect ourselves from the dark side of the digital future.

Travelling across the globe, from India to Estonia, Germany to Singapore, **Andrew Keen** investigates the best (and worst) practices in regulation, innovation, social responsibility, consumer choice and education - and shows what we can do to preserve human values in an increasingly digital world.

From the bestselling author of *The Cult of the Amateur* and *The Internet is Not the Answer*



'Keen has a sharp eye when it comes to skewering the pretensions and self-delusions of the new digital establishment'
Financial Times

“More drought. More floods. Rising sea levels… That’s one path we can take. The other path is to embrace the human ingenuity that can do something about it.”

BARACK OBAMA

“We’ve merely got to adapt to a hotter and a different world. It’s not necessarily a worse world.”

JAMES LOVELOCK

“We need an energy miracle. That may make it seem too daunting to people, but in science, miracles are happening all the time.”

BILL GATES

FROM THE MAKERS OF ***BBC FOCUS*** MAGAZINE